University of Nevada

Reno

Geothermal Occurrences in Truckee Meadows, Washoe County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrology

by

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August 1975

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August 1975

ACKNOWLEDGMENTS

Invaluable assistance was received from many sources during the course of this report. Richard L. Bateman made the original suggestion as to the aims and content of this study. Financial aid, instrumental in making this report possible, was received from federal funds administered by the Center for Water Resources Research, Desert Research Institute, University of Nevada System.

Thanks go to James Dinger and Richard L. Bateman who assisted in collection of water samples and editing of the report. Frank Spane and Dr. John Erwin aided in the compilation and interpretation of geophysical data.

A special word of thanks go to Dr. George Maxey, who consulted with the author on many subjects pertinent to this study.

ABSTRACT

Hot springs are numerous within Truckee Meadows area of northwestern Nevada. Most occur along the flanks of the Carson and Virginia Ranges. This study examines these thermal occurrences and looks at various aspects of each thermal area.

A shallow geothermal gradient of 52°C/Km has been established for Truckee Meadows. The high gradient could be related to a combination of high temperature upper mantle and a thin upper crust. It is possible that deep circulation of meteoric waters and the high geothermal gradient produce thermal waters. Surface occurrences then result from localization of the heated waters along fault zones.

Observed temperatures range from 180°C at Steamboat Springs, to 50°C at Lawton Hot Springs. Estimated reservoir temperatures, based upon SiO_2, Na-K, and Na-K-Ca geothermometers, are 201°C, 134°C, and 130°C for Steamboat, Moana and Lawton Hot Springs, respectively. Available data indicates an estimated heat discharge for Moana to be 1.96 BTU/sec. Assuming a steady state system exists for Moana, a conservative estimate of between 300 and 400 individual dwellings could make use of the thermal waters.

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INTRODUCTION

Location

The Truckee Meadows area is in northwestern Nevada (Figure 1), at the western edge of the Basin and Range physiographic province. The area exhibits a topography typical for the Basin and Range Province; that is, mountain ranges of moderate to high relief separated by alluvial basins. The basin comprising Truckee Meadows is at an elevation of 1340 meters and adjacent mountain peaks rise to over 3050 meters.

The study area is bordered on the west by the Carson Range, a portion of the Sierra Nevada, on the east by the Virginia Range, on the north by portions of these two ranges and to the south by Pleasant Valley (Figure 2).

The cities of Reno and Sparks are the major population centers found in Truckee Meadows, and have a combined population in 1974 of approximately 120,000 residents.

The principal surface drainage in the area is the Truckee River which originates at the controlled outlet for Lake Tahoe in the Sierra Nevada. The river flows 90 miles northeastward before it discharges into Pyramid Lake, a remnant of Pliestocene Lake Lahonton.

Climate and Vegetation

The climate for the Truckee Meadows area is arid to semiarid. The major factors controlling the precipitation are the Sierra Nevada and prevailing westerly winds. Moisture-laden air coming off the Pacific Ocean cools and condenses as it rises over the mountains. This results in the windward side of the Sierra Nevada experiencing heavy precipita-

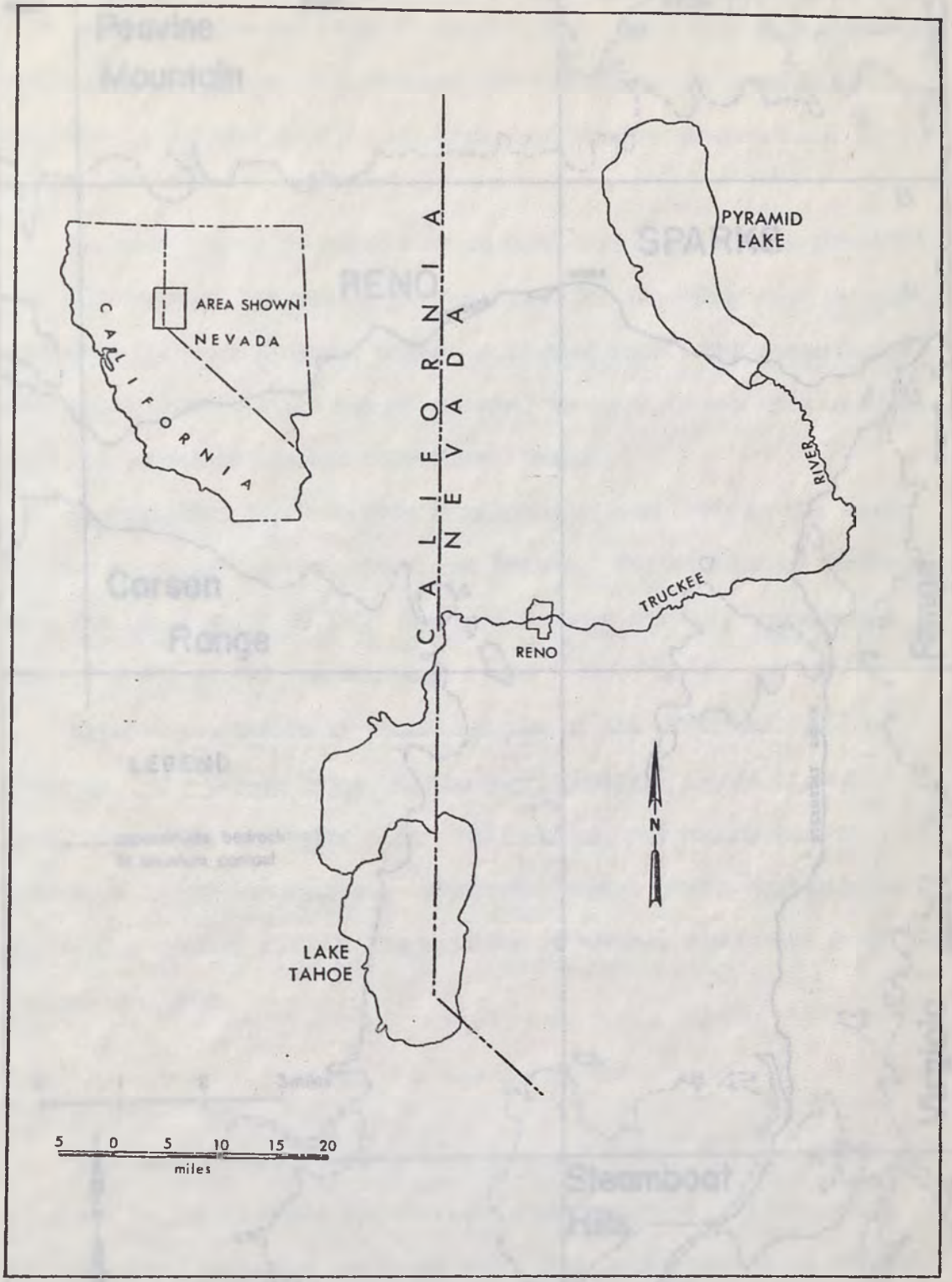

FIGURE 1. Location of Study Area

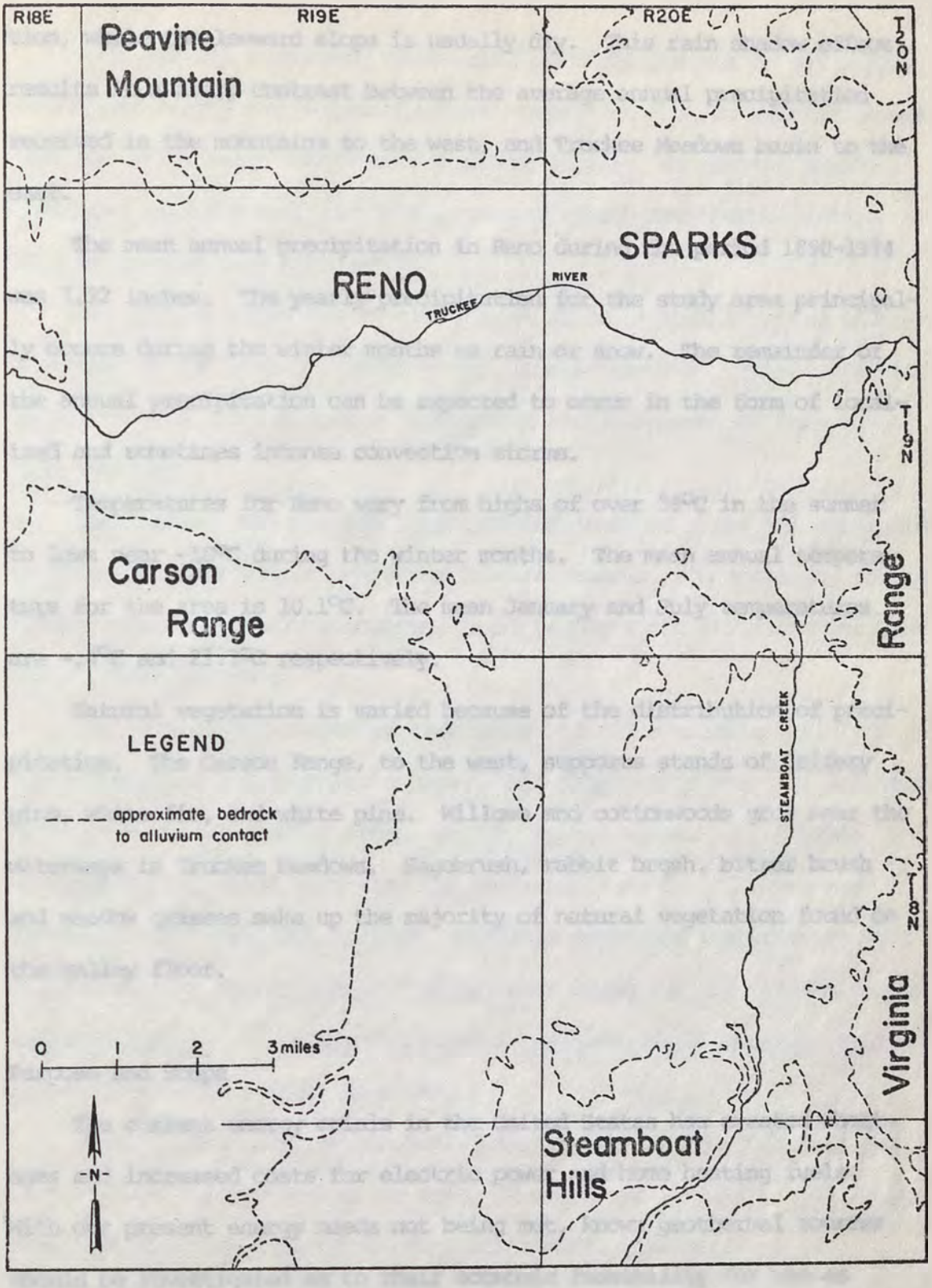

FIGURE 2. Truckee Meadows

tion, while the leeward slope is usually dry. This rain shadow effect results in a sharp contrast between the average annual precipitation received in the mountains to the west, and Truckee Meadows basin to the east.

The mean annual precipitation in Reno during the period 1890-1974 was 7.32 inches. The yearly precipitation for the study area principally occurs during the winter months as rain or snow. The remainder of the annual precipitation can be expected to occur in the form of localized and sometimes intense convective storms.

Temperatures for Reno vary from highs of over 38°C in the summer to lows near -18°C during the winter months. The mean annual temperature for the area is 10.1°C. The mean January and July temperatures are -.4°C and 21.3°C respectively.

Natural vegetation is varied because of the distribution of precipitation. The Carson Range, to the west, supports stands of Jeffery pine, white fir, and white pine. Willows and cottonwoods grow near the waterways in Truckee Meadows. Sagebrush, rabbit brush, bitter brush and meadow grasses make up the majority of natural vegetation found on the valley floor.

Purpose and Scope

The current energy crisis in the United States has created shortages and increased costs for electric power and home heating fuels. With our present energy needs not being met, known geothermal sources should be investigated as to their economic feasibility for use as alternate sources of energy.

With present technology Moana and Lawton Hot Springs do not supply sufficient energy for electrical power generation, but do provide enough heat for a hot water and domestic heating supply. If present trends continue, with the ever increasing cost of energy the thermal waters will be used to a greater extent.

The primary objective of this report is to provide a better understanding of the thermal systems within Truckee Meadows. This increased knowledge will help in future development and management of this valuable resource.

The initial phase of the investigation involved compiling available geophysical information concerning Truckee Meadows. In addition, information concerning surface geology, fault patterns and structure was obtained where possible.

The second phase involved examination of all available well logs for temperature and lithologic data. This information was used to better define the extent and occurrence of the thermal areas. In addition, an estimate of the total heat flow and permissible number of users was calculated for Moana Hot Springs. Possible reservoir temperatures were available. The three methods employed were based on: 1) silica concentrations (SiO_2), 2) sodium to potassium ratios (Na/K) and 3) sodium-potassium-calcium ratios (Na-K-Ca).

Finally, all existing chemical data for the thermal locations was used to more clearly define the areas of geothermal activity and, where possible, the direction of movement for thermal waters.

Previous Work

The first geologic work published concerning in part Truckee Meadows was conducted by the Fortieth Parallel Survey (King 1870, 1878). Louderback (1907) and Anderson (1909) produced some of the early published papers on the geology along the Truckee River.

Thompson and Sandburg (1958) described results of a gravity survey conducted from Washoe Valley to Reno. Cohen (1962) reported on occurrence of sulfate and uranium in the Truckee Meadows ground-water. The hydrogeology and hydrogeochemistry of Truckee Meadows was described by Cohen and Loeltz (1964). Thompson and White (1964) published a report on the geology of Steamboat Springs thermal area, which included geologic maps (1:62,500) of the Virginia City and Mount Rose quadrangles. Waring (1965) listed known thermal springs for Truckee Meadows. White (1968) published a report on hydrology and heat flow from Steamboat Springs. Geology and mineral deposits of Washoe county were described by Bonham (1969) including brief discussions on mineral deposits of Steamboat Springs and Wedekind areas.

Fournier and Rowe (1966) were first in developing a quantitative estimate of thermal-aquifer temperatures based upon the solubility of silica. Fournier and Truesdell (1973) used an empirical method based upon molar Na, K, and Ca concentrations for estimation of the last temperature of water-rock interaction. Fournier, White and Truesdell (1974) presented the basic assumptions for using geochemical indicators for estimation of subsurface temperatures.

Bingler and others (1974 and 1975) published a series of environmental maps on a scale of 1:24,000 for Truckee Meadows, including

geologic and hydrologic properties. A text by Bingler and others accompanying the maps will be published soon. Bateman and Scheibach (1975) conducted an evaluation of present use of geothermal resources in Truckee Meadows. Mizell (1975) has mapped much of the surficial geology of Truckee Meadows for her Masters Thesis. Erwin (unpublished) has completed a gravity survey of Truckee Meadows on a scale of 1:24,000.

GEOLOGY

The Carson and Virginia Ranges surrounding Truckee Meadows are faultblock mountains consisting of metamorphic, plutonic and volcanic rocks. Both mountain ranges exhibit a similar geologic framework and history.

The Carson and Virginia Ranges consist primarily of a biotite-hornblende granodiorite which was emplaced into metavolcanic and metasedimentary rocks. The plutonic rocks, based upon radioactive age dates, have been assigned to the Cretaceous Period (Curtis and others, 1958).

Early in the Tertiary Period the area was deformed, with normal faulting and extrusion on lava and pyroclastics taking place. Normal faulting and volcanism continued during the Upper Eocene, Oligocene, Miocene and Pliocene times (Cohen and Loeltz, 1964). The Tertiary volcanics, predominately andesite flows, flow-breccias, tuff-breccias and intrusives, uncomformably overly the granodiorite and metamorphic rocks of both mountain ranges. These andesite flows are mainly confined to the Alta and Kate Peak Formations (Cohen and Loeltz, 1964). The Alta Formation, found primarily in the Virginia Range, has been assigned to the Oligocene (Axelrod, 1949) based upon fossil leaf identification. The Kate Peak Formation is found in both Virginia and Carson Ranges and intertongues with lacustrine deposits of the Truckee Formation which, based upon fossil evidence, has been assigned an age near the Miocene-Pliocene boundary (Calkins, 1944).

The bulk of unconsolidated deposits found in Truckee Meadows is composed of the Truckee Formation (Cohen and Loeltz, 1964), consisting mainly of fine-grained unconsolidated and partially consolidated lacustrine deposits. Interbedded in the Truckee Formation are lenses of relatively pure diatomite along with diatomaceous clay, silt and sand. It also contains minor amounts of alluvial fan and stream channel deposits. The alluvial fan deposits appear to be restricted to the oldest portions of the formation (Cohen and Loeltz, 1964).

During the deposition of the Truckee Formation normal faulting intensified and the present topography began to evolve. The Truckee River drainage system was developed at this time. Gradual uplifting of the Virginia Range blocked the Truckee River, resulting in the formation of a lake in Truckee Meadows. Development of a water gap east of Reno allowed normal downstream movement of the Truckee River to resume. This cycle of the formation of a lake, the drainage through a water gap, was repeated several times (Cohen and Loeltz, 1964).

Volcanic activity resumed with the deposition of the Lousetown Formation, consisting of lava flows ranging in composition from andesite to olivine basalt. Paleomagnetic evidence indicates an age of early Pleistocene or late Pliocene for the Lousetown Formation (Thompson, 1956).

Quaternary deposits of Truckee Meadows are divided into three main categories by Bingler (1975): 1) Truckee River deposits, consisting mainly of boulder outwash 2) Alluvial fan deposits found entirely along the margins of the meadows 3) Reworked older deposits and their deposition in the central portion of Truckee Meadows.

Table 1. Distribution of Mesozoic, Tertiary and Quaternary rocks in the Truckee Meadows area, Nevada

AGE		ROCK UNIT	LITHOLOGY	DISTRIBUTION
QUATERNARY	Pleistocene	Tahoe Outwash	Boulder to cobble gravel, sandy gravel and gravely sand. Contains giant boulders.	Truckee Meadows
	Pleistocene	Donner Outwash	Deposits similar to Tahoe Outwash except weathered to depths of four feet or more.	Truckee Meadows
	Pliocene–Pleistocene	Lousetown Formation	Lava flows ranging from andesite to olivine basalt.	Carson Range and Virginia Range
TERTIARY	Early Pliocene	Truckee Formation	Fine-grained unconsolidated to partially consolidated lacustrine sediments with interbedded diatomaceous clay, silt and sand. Also contains stream-channel and alluvial-fan deposits.	Truckee Meadows
	Miocene–Pliocene	Kate Peak Formation	Porphyritic hornblende-biotite andesite flows containing phenocrysts of plagioclase, biotite and hornblende. Commonly altered.	Carson Range and Virginia Range
	Oligocene	Alta Formation	Pyroxene andesite flows, flow breccia and laharic breccia. Commonly altered.	Carson Range and Virginia Range
MESOZOIC	Cretaceous	Intrusive Rocks	Predominately hornblende-biotite granodiorite.	Carson Range and Virginia Range

Structure

Truckee Meadows is near the western border of the Great Basin. The Meadows is a structural depression, trending north-south, and flanked by the Virginia and Carson mountain ranges on the east and west respectively. Moderate to steeply dipping faults border the basin. Thompson and White (1964) describe the northern portion of Carson Range as a faulted anticlinal uplift. They suggest that the domical feature of the mountain range may be related to concealed Tertiary intrusions.

The basin has been in existence at least since early Pliocene, when the Truckee Formation was deposited. Quaternary faults are found throughout Truckee Meadows. The existence of one single master fault is not indicated though several groupings of Quaternary faults, all of relatively short fault traces, are found (Bingler, 1975).

An alluvial basin, such as Truckee Meadows, provides favorable conditions for the use of gravity measurements for concealed structure delination because of the large density contrast between basin sediments and the underlying bedrock. An estimation of basin sediment thickness based on gravity determinations can indicate the location and character of concealed structural breaks. Thompson and Sandberg (1958) first described the concealed structure of Truckee Meadows based on gravity measurements. They computed that at its deepest point, east of Reno, the basin contains approximately 850 meters of sediment. The data indicates the existence of a major structural break about 1.5 kilometers west of the Virginia Range. Along the foot of the Carson Range the gradients are in general more gentle. According to Thompson and Sanberg

(1958) this gentler slope could indicate a fault scarp which has been extensively eroded before deposition of basin sediments, or where a number of separate faults have distributed the major displacement.

A more recent gravity survey (Erwin, unpublished) has established the existence of a buried structure in the Moana Hot Springs area (Plate 1). Depth to bedrock is approximately 305 to 370 meters (Erwin, personal communication) in this area. The bedrock forms a ridge, with alluvium being up to 180 meters deeper on either side of the ridge. Surface expression for faulting also parallels the buried ridge and may be directly related to this feature. A well above the structure, 335 meters deep, never encountered bedrock.

GEOTHERMOMETRY

In an attempt to determine thermal-aquifer temperatures the chemical concentrations of certain dissolved constituents have been used. This has resulted in both qualitative and quantitative estimates.

Among the qualitative indicators is the chloride to fluoride ratio, where high (over 100) ratios indicate elevated temperatures (Mahon, 1970). Low values for the magnesium to calcium ratio tend to indicate high aquifer temperatures (White, 1970). Mahon (1970) found high ratios of sodium to calcium indicative of high temperatures.

Quantitative estimates of thermal-aquifer temperatures are based on silica solubility, sodium to potassium (Na/K) ratio, and the ratio of sodium-potassium-calcium (Na-K-Ca) (Fournier and Rowe, 1966; White 1965, Fournier and Truesdell, 1973). Certain basic assumptions are made in the use of these geothermometers. They are as follows (Fournier, White, and Truesdell, 1974):

1. Temperature dependent reactions occur at depth.
2. There is an adequate supply of the constituents that are used as a basis for geothermometry.
3. Water-rock equilibrium occurs at the reservoir temperature.
4. There is negligible re-equilibrium at the lower temperatures as the water flows from the reservoir to the surface.
5. There is no dilution or mixing of the hot water coming from depth with shallow water.

SiO_2 Geothermometer

At present silica is the only chemical indicator which is unaffected by the local mineral suite, other dissolved constituents, and gas partial pressures. Amount of silica in solution for most hot springs is primarily controlled by solubility of quartz at depth (Fournier and Rowe, 1966). Therefore, silica concentration of emerging waters from thermal springs can give an estimate of the temperature at which the thermal water was last in equilibrium with quartz.

Fournier and Rowe (1966) found experimentally that the maximum silica concentration likely to be found at depth is approximately 725 ppm at 330°C. To find approximate silica content of the thermal water when it reaches the surface, a correction is made for steam loss which would occur during its ascent from a high pressure environment at depth to atmospheric pressure at land surface.

As thermal water moves toward the surface, at some temperature below critical temperature, hydrostatic head decreases and at some point pressure will be low enough for boiling to occur provided little heat is lost by conduction to country rock. Steam or gas will form resulting in a decrease in temperature due to the latent heat of vaporization required to form the gas phase. This process will continue as thermal waters move toward the surface resulting in concentration of nonvolatile constituents, including silica.

Rising thermal waters may be considered to be at either constant entropy or constant enthalpy. For the condition of constant entropy it is assumed that no heat is lost to surrounding wall rock, and equilibrium is maintained between liquid and gas while moving toward the

surface. Constant enthalpy assumes no heat loss to wall rock, but equilibrium is not maintained between liquid and gas phases.

In thermal systems where country rock has been in contact with hot waters for a long time, removal of heat from thermal waters into country rock can be considered to be negligible in comparison to the decrease in temperature resulting from boiling. Therefore, adiabatic cooling can be approximated in underground thermal systems either at constant entropy or enthalpy.

Figure 3 has been adapted from Fournier and Rowe (1966). This graph assumes that a certain percentage of the thermal water vaporizes to steam during its upward movement. Using steam tables compiled by Keenan and others (1969) an estimation of the fraction of vapor separation is possible. The following equation is used to obtain the amount of steam formed, assuming that the thermal water initially was at 260°C and 46 atmospheres and came to the surface at 100°C and 1 atmosphere:

$$X(h_{fg260}) = (1-X)(h_{f260} - h_{f100}) + X(h_{g260} - h_{g100})$$

where X equals fraction of vapor formed, h_f is enthalpy of the liquid in equilibrium with vapor, h_g equals change in enthalpy by evaporation. The same equation is used for the condition of constant entropy, by using entropy values presented by Keenan and others (1969).

Once the percentage of steam formed, either at constant entropy or enthalpy, has been determined a silica concentration in residual thermal water after steam separation may be found. Quartz solubilities for various temperatures presented in Appendix I are used in the calcu-

lations. For example, at 260°C and 46.3 atm to 100°C and 1 atm, 32% of the original water would be converted to steam, assuming constant enthalpy. The solubility of quartz at this temperature and pressure is approximately 540 ppm. The resulting silica concentration in solution after steam separation would be:

$$794 \text{ ppm silica} = \frac{540}{(1-.32)(10^6-540) + 540}$$

Original curves for temperature determination based on silica, presented by Fournier and Rowe (1966) have been revised (Personal Communication) and curves presented in Figure 3 are from updated information.

The constant enthalpy curve can be approximated by the equation:

$$^{o}C = \frac{1522}{5.75 - \log_{10} \text{ of } SiO_2 \text{ con. mg/kg}} - 273^{o}C$$

while the constant entropy curve can be expressed as:

$$^{o}C = \frac{1309}{5.19 - \log_{10} \text{ of } SiO_2 \text{ con. mg/kg}} - 273^{o}C$$

Na-K Geothermometer

Numerous authors (e.g., Orville, 1963; White, 1965; and Ellis, 1970) have developed empirical curves showing variation of concentration of Na/K as a function of the reciprocal of absolute temperature (Figure 4).

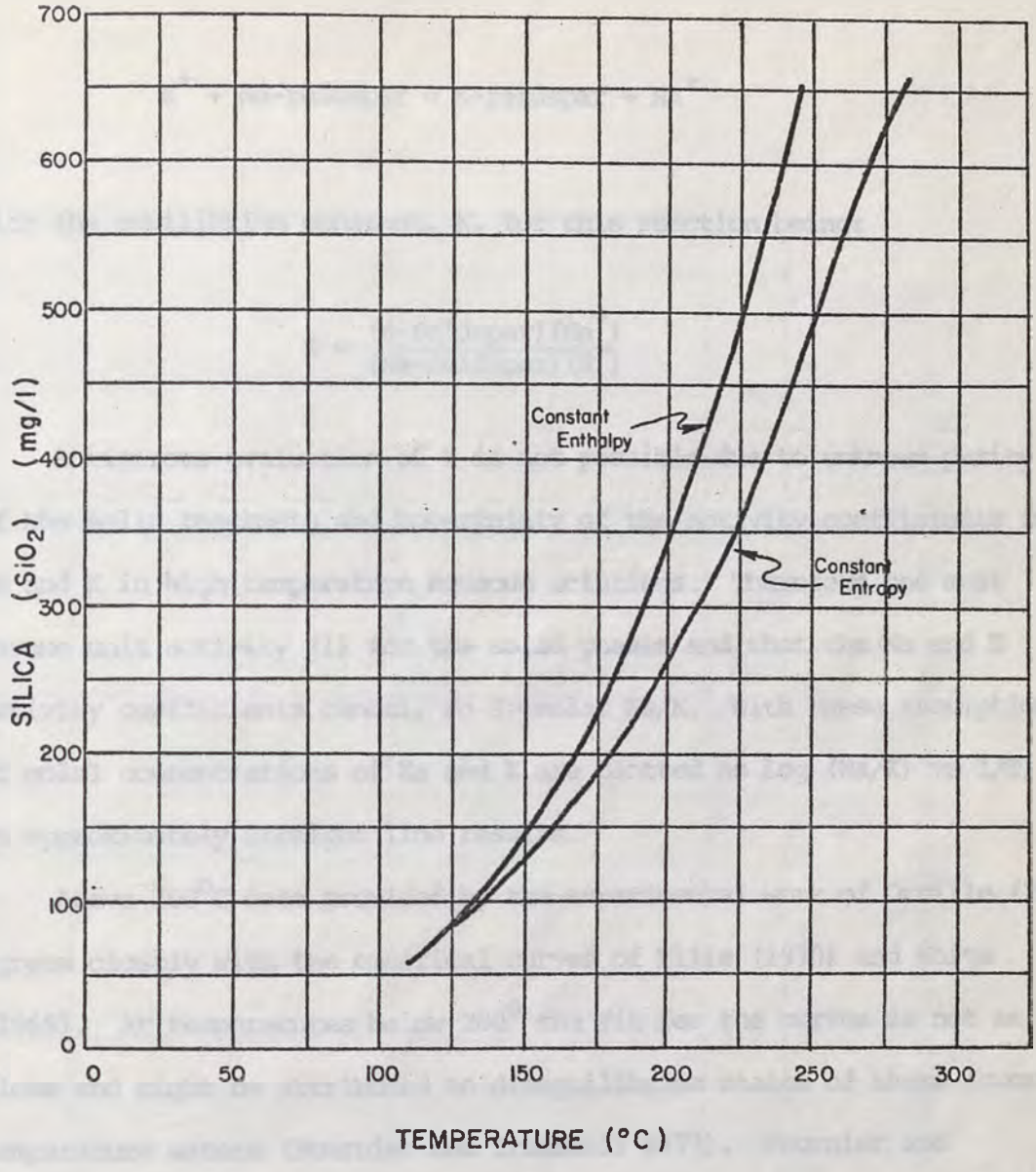

FIGURE 3. Silica Concentration vs. Temperature

The Na-K geothermometer is based on the reaction:

$$K^+ + \text{Na-feldspar} = \text{K-feldspar} + Na^+$$

with the equilibrium constant, K, for this reaction being:

$$K = \frac{(\text{K-feldspar})(Na^+)}{(\text{Na-feldspar})(K^+)}$$

A rigerous evaluation of K is not possible due to unknown purity of the solid reactants and uncertainty of the activity coefficients for Na and K in high temperature aqueous solutions. Therefore one must assume unit activity (1) for the solid phases and that the Na and K activity coefficients cancel, so K≈molar Na/K. With these assumptions, if molal concentrations of Na and K are plotted as Log (Na/K) vs 1/T, an approximately straight line results.

Above 200°C data provided by the experimental work of Orville (1963) agrees closely with the empirical curves of Ellis (1970) and White (1965). At temperatures below 200° the fit for the curves is not as close and might be attributed to disequilibrium states of these lower temperature waters (Fournier and Truesdell 1973). Fournier and Truesdell (1970) showed that for any given temperature the specific reaction taking place controls the Na/K ratio. Therefore numerous Na/K vs temperature curves are possible.

Due to questionable results obtained by using the Na-K geothermometer extreme caution should be employed in its use. Where possible

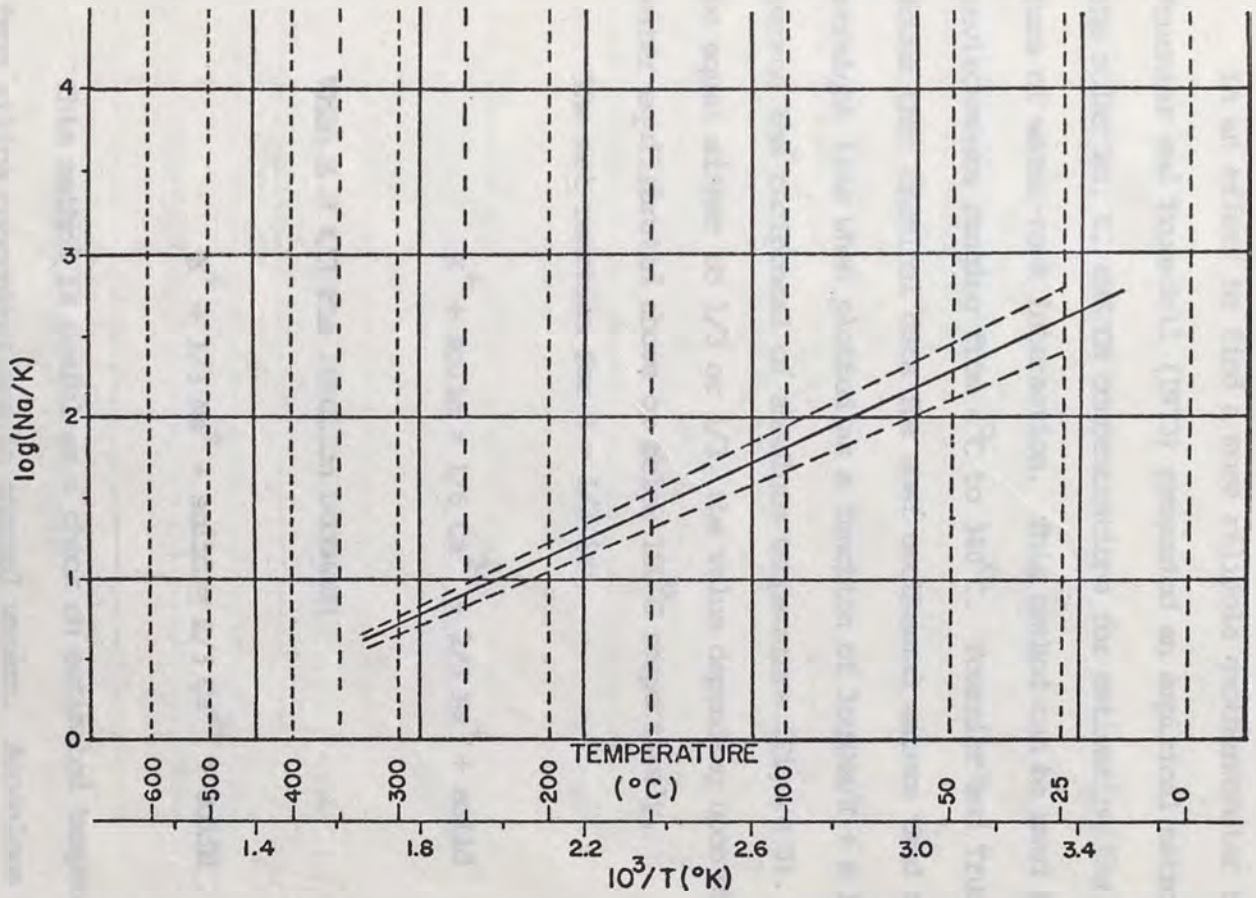

FIGURE 4. Empirical Correlation of Na-K Ratio with Temperature

it should be used only for natural waters exhibiting other evidence of high temperature at depth.

Na-K-Ca Geothermometer

In an effort to find a more reliable geothermometer than Na-K, Fournier and Truesdell (1973) presented an empirical method based upon the molar Na, K, and Ca concentrations for estimating the last temperature of water-rock interaction. This method can be used in temperature environments ranging from 4°C to 340°C. Fournier and Truesdell (1973) found that chemical data for most geothermal waters tend to lie near a straight line when plotted as a function of $\log(Na/K + B \log(\sqrt{Ca}/Na)$ versus the reciprocal of absolute temperature (Figure 5). Beta (B) may be equal either to 1/3 or 4/3, the value depending upon whether the water equilibrated above or below 100°C respectively.

The net reaction for B = 1/3 is:

$$K^+ + \text{solid} = 1/6\ Ca^{2+} + 2/3\ Na^+ + \text{solid}$$

When B = 4/3 the reaction becomes:

$$K^+ + 1/3\ Na^+ + \text{solid} = 2/3\ Ca^{2+} + \text{solid}$$

This method is useful as a check on estimated temperatures derived from silica concentrations in thermal waters. Anomalous temperature values may result if water-rock reactions continue to occur during ascent. If the thermal waters continue to dissolve additional Ca the

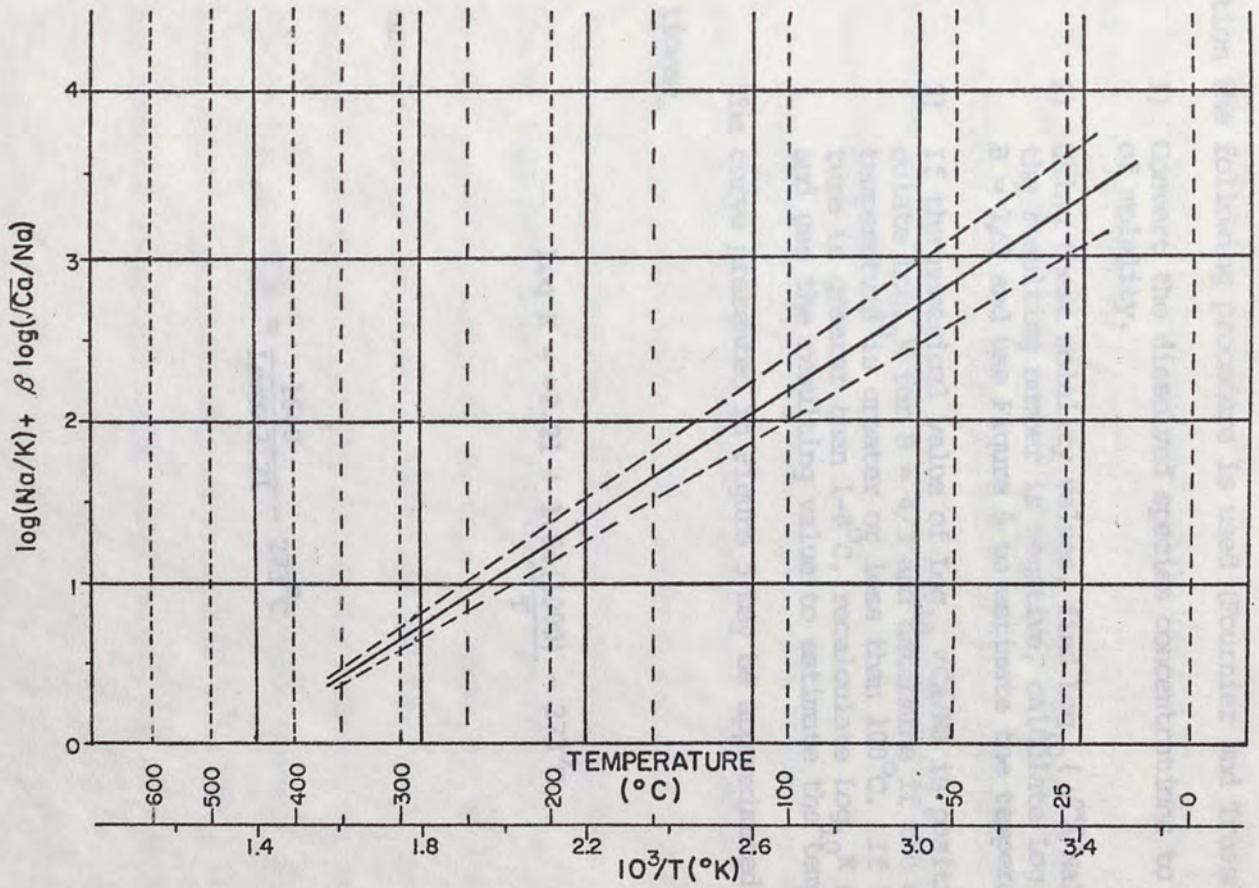

FIGURE 5. Empirical Correlation of Na-K-Ca Ratio with Temperature

the resulting estimated aquifer temperature will be too low. Estimated temperatures may be too high if Na and K are prevented from reacting with country rock due to high initial concentrations of Ca.

To obtain an estimate of the temperature of water-rock equilibration the following procedure is used (Fournier and Truesdell 1973):

1) Convert the dissolved species concentrations to units of molality.

2) Using these molality values, find $\text{Log}_{10}(\sqrt{\text{Ca}}/\text{Na})$. If the resulting number is negative, calculate $\text{Log}_{10}K$ for B = 1/3 and use Figure 5 to estimate the temperature.

3) If the numerical value of $\text{Log}_{10}\sqrt{\text{Ca}}/\text{Na}$ is positive, calculate $\text{Log}_{10}K$ for B = 4/3 and determine if the estimated temperature is greater or less than 100°C. If the temperature is greater than 1-0°C, recalculate $\text{Log}_{10}K$ using B = 1/3 and use the resulting value to estimate the temperature.

The curve presented in Figure 5 may be approximated by the equations:

$$\text{Log } K = -2.21 + 1.64\frac{(1000)}{T} - 273^{\circ}\text{C}$$

or

$$T^{\circ}\text{C} = \frac{1640}{\text{Log}K+2.21} - 273^{\circ}\text{C}$$

THERMAL ACTIVITY

Truckee Meadows is an area of considerable geothermal activity (Figure 6). Prominent thermal areas in the Meadows include Steamboat Springs, Moana Hot Springs and Lawton Hot Springs. These three source areas lie within a thermal zone approximately 12 miles long at the foot of the Carson Range.

The occurrence of thermal activity is not restricted to these three areas alone. Hot springs and other evidence indicating thermal activity has been found in the Wedekind mining district and several unnamed areas in Truckee Meadows.

Steamboat Springs has been extensively studied by White (1964, 1968, 1974) and is the hottest thermal area located within Truckee Meadows. Temperatures of 170°C have been recorded and estimated reservoir temperatures are over 200°C for Steamboat Springs. The commercial use of this potential power source has been halted, at present, because of the corrosive nature of the waters. Moana Hot Springs is cooler with known temperatures reaching 95°C, and has been used, to a limited extent, since the turn of the century as a source for domestic heating. Lawton Hot Springs located along the Truckee River 5 miles west of Reno, exhibits surface temperatures of 45-50°C. This thermal spring has been the site of a small health resort for some 85 years.

Steamboat Springs

In the extreme southern portion of Truckee Meadows (Figure 6) is one of the most thoroughly investigated thermal areas in the world,

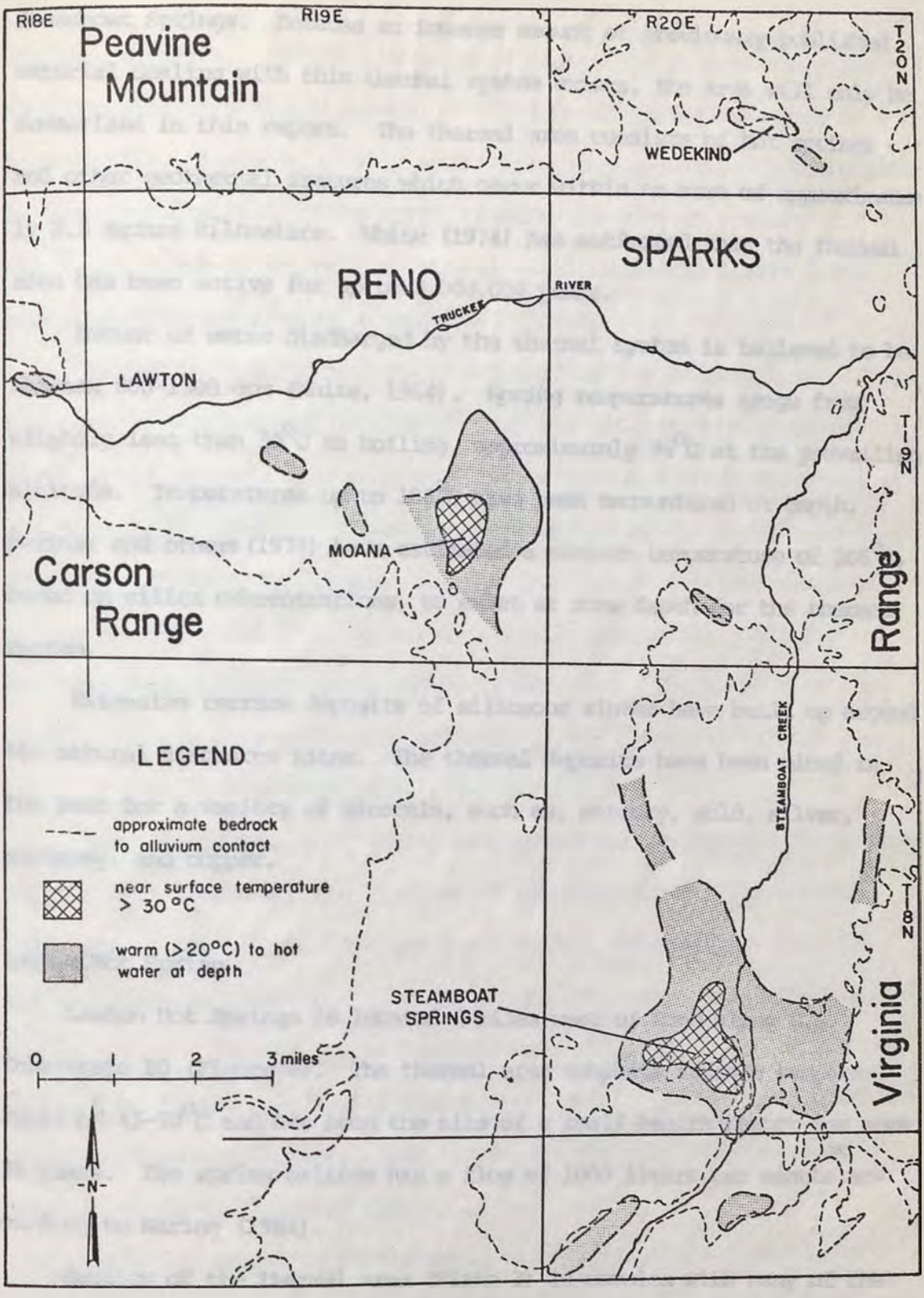

FIGURE 6. Location of Known Thermal Areas in Truckee Meadows

Steamboat Springs. Because an immense amount of previously published material dealing with this thermal system exists, the area will only be summarized in this report. The thermal area consists of hot springs and other geothermal features which occur within an area of approximately 2.5 square kilometers. White (1974) has estimated that the thermal area has been active for up to 3,000,000 years.

Amount of water discharged by the thermal system is believed to be between 800-1300 gpm (White, 1964). Spring temperatures range from slightly less than 50°C to boiling, approximately 96°C at the prevailing altitude. Temperatures up to 186°C have been encountered at depth. Mariner and others (1974) have estimated a minimum temperature of 206°C, based on silica concentrations, to exist at some depth for the thermal system.

Extensive terrace deposits of siliceous sinter have built up around the natural discharge sites. The thermal deposits have been mined in the past for a variety of minerals, such as, mercury, gold, silver, antimony, and copper.

Lawton Hot Spring

Lawton Hot Springs is located 5 miles west of Reno along U.S. Interstate 80 (Figure 6). The thermal area exhibits surface temperatures of 45-50°C and has been the site of a small health resort for some 85 years. The spring orifice has a flow of 1000 liters per minute according to Waring (1964).

Geology of the thermal area (Plate 3) is complex with many of the contacts, faults and other features being hidden by recent outwash and

alluvial deposits. The area is primarily comprised of Quaternary outwash deposits with lesser amounts of Tertiary andesites and Mesozoic granodiorite. Axelrod (1958) mapped the surrounding area, though excluded the thermal area. Bonham (1969) covered the area at a scale of 1:250,000, which is impractical to work with. Recently Nimsic (1974) mapped the thermal area at a scale of 1:12,000.

The spring is approximately 10 meters from the Truckee River along the trace of north-south trending fault. The close proximity of the river to the thermal spring strongly suggests that a great amount of mixing occurs. Estimated reservoir temperatures by the various geothermometers are listed in Appendix V. The temperature estimate based on silica concentration gives an unrealistically low value. This may be the result of mixing with the nearby river water. The Na-K-Ca geothermometer gives a more reasonable estimate of 109°C and 147°C, when Beta equals 4/3 and 1/3 respectively.

Fournier and Truesdell (1974) have presented two methods for estimation of temperature and the fraction of hot water that is mixed with cold water. The calculations for their methods depend upon the silica concentration and temperature of the non-thermal ground-water before mixing occurs. The non-thermal ground-water temperature may be assumed to be equal to the mean annual temperature, 9.2°C. Silica concentration for non-thermal ground-water near Lawton Hot Springs is unknown and an estimate of 25 ppm has been used.

Of the two models to be presented the first gives a probable minimum temperature. In the first model it is assumed that enthalpy of the hot water (plus steam) which heats the cold water is identical to the

initial enthalpy of the hot water at depth. The problem may be solved graphically as follows (Fournier and Truesdell, 1974):

1) Assume a series of enthalpy values of hot water for temperatures listed in Appendix I, and evaluate an X_t value for each one.

$$X_t = \frac{\text{(Enthalpy of hot water)} - \text{(Temperature of warm spring)}}{\text{(Enthalpy of hot water)} \quad \text{(Temperature of cold spring)}}$$

2) Plot X_t vs temperature of the assumed hot water enthalpy value.

3) Assume a series of silica concentrations based on temperatures listed in Appendix I and calculate X_{Si} for each silica concentration.

$$X_{Si} = \frac{\text{(Silica in hot water)} - \text{(Silica in warm spring)}}{\text{(Silica in hot water)} - \text{(Silica in cold spring)}}$$

4) On the same graph used before plot X_{Si} vs the temperature corresponding to the silica concentration at that temperature.

5) The intersection of the two lines gives the estimated temperature of the water before mixing and the fraction of cold water mixed.

The resulting values are presented in Figure 7 and Appendix II. The two lines intersect at a temperature of 130°C with the fraction of cold water mixed being .67.

The second model is based on the equation:

$$\text{Residual Silica} = \frac{\text{Original Silica}}{1-y}$$

where y is the fraction of steam formed. If one assumes that t_x, the

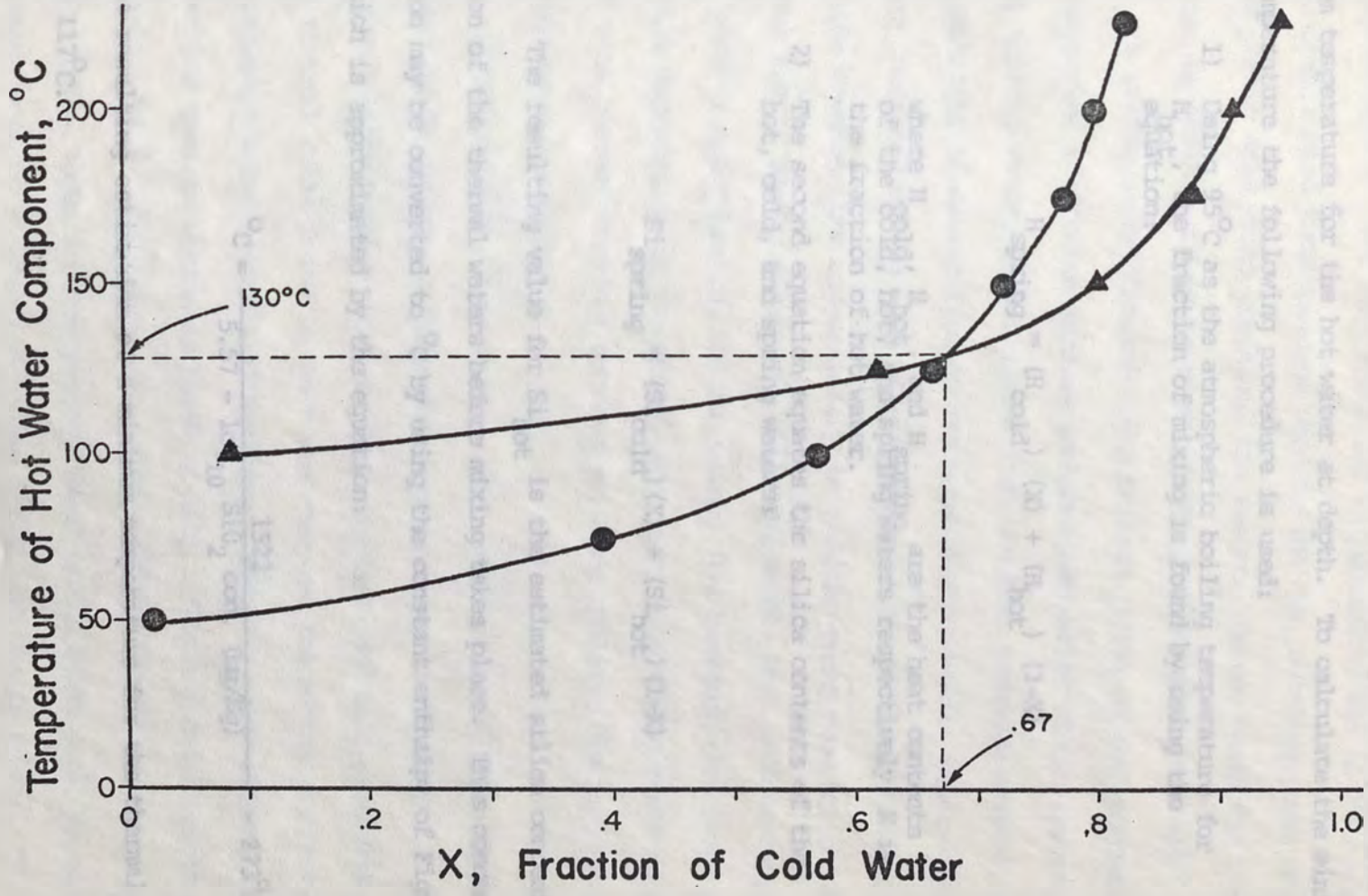

FIGURE 7. Temperature of Hot Water Component vs. Fraction of Cold Water for Lawton Hot Springs

temperature at which steam escapes, equals the boiling temperature for the altitude, 95°C in this case, the method will yield a probable minimum temperature for the hot water at depth. To calculate the minimum temperature the following procedure is used:

1) Using 95°C as the atmospheric boiling temperature for H_{hot}, the fraction of mixing is found by using the equation:

$$H_{spring} = (H_{cold})\ (X) + (H_{hot})\ (1-X)$$

where H_{cold}, H_{hot}, and H_{spring} are the heat contents of the cold, hot, and spring waters respectively; X is the fraction of hot water.

2) The second equation equates the silica contents of the hot, cold, and spring waters:

$$Si_{spring} = (Si_{cold})\,(X) + (Si_{hot})\,(1-X)$$

The resulting value for Si_{hot} is the estimated silica concentration of the thermal waters before mixing takes place. This concentration may be converted to °C by using the constant enthalpy of Figure 3, which is approximated by the equation:

$$^{o}C = \frac{1522}{5.57 - \log_{10} SiO_2 \text{ con. (mg/Kg)}} - 273^{o}C$$

The resulting estimation of a minimum temperature for the thermal spring is 117°C.

Moana Hot Springs

Shortly before 1905 the Moana Hot Springs resort (Figure 6) came into existence. The area increased in popularity and in 1907 a railway was constructed from downtown Reno to the spa, swimming pool, dance hall and picnic area which comprised the resort. During World War I business began to decline and never regained the popularity it once had.

A recent study (Bateman and Scheibach, 1975) on the geothermal occurrences in Truckee Meadows included evaluation of the present use of the thermal water, investigation into the heat exchange systems, and the possibility of degradation of the potable ground-water supply resulting from increased mixing with thermal water of Steamboat springs and Moana. At the present time approximately 35 dwelling units near the original Moana resort employ geothermal wells and simple heat exchange systems to provide space heating and hot water. The research also found that little degradation of the ground-water supply is taking place at present and with current trends a decrease in water quality, due to thermal occurrences, is unlikely.

Observed water temperatures range from 75°C to 96°C for depths in excess of 30 meters. Estimated reservoir temperatures listed in Table 2 show resulting temperatures for Na-K, Na-Ca-K, and SiO_2 geothermometers for thermal wells found in the Moana area and the average estimated temperature based upon all 12 analyses. There is close agreement between the average estimates based on SiO_2, adiabatic and conductive, and Na-Ca-K with B = 4/3; these are 132°C, 136°C and 134°C respectively.

Plate 2 shows surface geology found in the Moana area, based on previous work by Bingler and Bonham (1973) and Mizell (1975). The area

Table 2. Estimated Thermal Aquifer Temperatures for Moana Hot Springs

Location	Observed Temperature °C	Estimated Temperature °C				
		Na/K	Na/K+1/3 Ca/Na	Na/K+4/3 Ca/Na	Silica Adiabatic	Silica Heat Conduction
T19N R19E 24 BBA	42	101	127	101	134	139
T19N R19E 24 BCDB	59	124	148	123	125	128
T19N R19E 24 CABA	47	137	158	129	126	129
T19N R19E 25 CBBB	61	105	126	91	129	133
T19N R19E 26 ADA	85	101	127	98	129	133
T19N R19E 26 ADAA	84	105	132	113	139	145
T19N R19E 26 ADAB	85	109	135	110	138	143
T19N R19E 26 DABA	80	105	128	99	135	139
T19N R19E 26 ADCC	90	116	133	89	147	155
T19N R19E 26 ADDA	78	101	127	101	134	139
T19N R19E 26 ADDD	90	107	129	97	134	139
T19N R19E 26 DACB	85	112	134	100	136	141
Average Estimated Temperature °C		111	130	104	132	136

is primarily composed of unconsolidated small cobble gravels and interbedded coarse sand of the Donner Lake outwash deposit. Quaternary alluvium covers the remainder of the area.

The numerous faults found within the thermal area comprise a segment of one of the three swarms of Quaternary fault traces located along the base of the Carson Range (Bingler, 1975). Bingler (1975) believes that the last movement along these faults took place sometime after the Illinoian ice age, approximately 115,000 years ago. This estimate is based upon stratigraphic evidence.

Faults are believed to be the primary control for Moana thermal system. Because of present urbanization, surface expression of faulting cannot be directly traced to the main thermal area. The buried structure defined by Erwin's gravity survey (1974) parallels the surface expression for faulting. This information may be interpreted as further indication that faulting is the major controlling factor.

Water table displacements, due to the north-south trending faults which pass through Sweetwater Lane (T19N R19N 26 ADD) offset the water table by 4-6 meters. Cooley and others (1971) believe that this water table displacement, or stair-stepping, is a common occurrence along many faults in the area. Initial water table elevations in the principal thermal area range between 12 and 15 meters below the land surface. However, upon completion of a typical thermal well the water table has risen to within 4 meters of the surface.

Recent volcanism is not indicated in the Moana area. The thermal water may be the result of either a shallow intrusive body or deep circulation of meteoric water along faults with the heat resulting from

the high regional thermal gradient. The thermal system can basically be described as follows: 1) cool water, high in sulfate from the bleached rock areas above Moana, percolate downward, 2) these cool waters are heated because of deep circulation, or contact with a shallow heat source and the resulting density decrease causes the water to move upward, starting a convective system.

Approximate age of this thermal system may be arrived at indirectly. If one assumes that faulting is and has been the primary control for Moana, then the last movement along the fault(s) should give a minimum estimate of the age of the thermal system. Last movement of the faults in Moana is believed to have been post-Illinoian and pre-Wisconsinan (Bingler, 1974). This gives the thermal system a minimum age between 115,000-85,000 years. Assigning a miximum age is much more difficult. There are no spring deposits for any thermal area, except Steamboat, which may be age dated. If one assumes the thermal occurrences throughout Truckee Meadows came into existence at approximately the same time, then based upon age dates for Steamboat Springs, a maximum age of 3 million years could be indicated for Moana. The actual age of the thermal system likely falls within the above minimum and maximum ages.

Dispersed Area

Several small disconnected areas of thermal activity are found within Truckee Meadows (Figure 6). Most areas show no surface evidence, i.e. springs, etc., indicating the presence of thermal water, but warm to hot water has been encountered at varying depths in wells and in one case a mine shaft.

The Wedekind Mining district, located in the foothills north of the city of Sparks, halted production in 1903, partly due to the occurrence of "hot" water at a depth of 213 feet (Bonham, 1969). Attempts were made to pump the shaft dry, but a 600 lpm pump was only able to hold the hot water at the 100 foot level. No further information concerning this thermal area is available at the present time.

Other documented evidence of thermal occurrences along the foot of the Carson Range includes several deep wells in sections 21 and 22 of T19N R19E, which encountered "hot" water at a depth of 366 meters and 244 meters respectively. Between Steamboat Springs and Moana, Waring (1964) lists three thermal springs, Huffaker, Zolezzi, and Da Monte. Confirmation of the location or existence of these springs was attempted without success. Spring locations given by Waring (1964) are poor and this may be the reason for lack of confirmation on their existence.

Geologic maps, along the base of the Carson Range, by Bingler (1974), Thompson and White (1964), and Cohen and Loeltz (1964) do not show a single master fault. The mappable faults tend to lie in groups or swarms of relatively short fault traces, with no single fault visible for more than 2-3 kilometers. The minor thermal occurrences parralleling the Carson Range, from Steamboat Springs in the south, north to Lawtons Hot Springs (T19N R18E) are no doubt related to the major geothermal areas. Whether they are mixed waters directly from Steamboat and Moana, or from deep circulation of meteoric, is unknown at present. More chemical data from the minor occurrences could give a better idea as to their origin.

If the minor occurrences are mixed waters eminating along faults, then one might assume that thermal water could be encountered at depth anywhere along this linear zone. However, if deep circulation along several small but deep faults is responsible for these minor thermal occurrences then their areal extent may be much more limited.

Several small thermal areas exist along the eastern margin of the valley and are assumed to be related to faults along the base of the Virginia Range. These areas typically have temperatures under 20°C and possibly are mixed waters from Steamboat Springs or owe their thermal characteristics to moderately deep circulation.

ESTIMATE OF HEAT DISCHARGE BY CONDUCTION

Surface discharge, i.e. springs, for Moana is at present almost nonexistent. A method based on heat discharge by conduction presented by Olmsted and others (1975) can be applied to the Moana area to obtain a crude estimate of the heat discharged.

Linear thermal gradients in strata of similar thermal conductivity indicates conductive heat flow. An estimate of the thermal conductive heat flow is based upon the observed thermal gradients and estimated thermal conductivities of the materials encountered while drilling. Fourteen wells with well logs and temperature data were used in the calculations.

Heat flow through a series of horizontally stratified beds of varying thermal conductivities is equal to the thermal gradient for the entire section multiplied by the harmonic mean of the thermal conductivities. For a series of beds the harmonic mean (K_m) is:

$$K_m = \frac{Zi}{Z_i/K_i}$$

where Z_i equals the thickness of bed i, in meters, and K_i equals the estimated thermal conductivity of bed i.

Estimate for thermal conductivities in the area were based on observed lithologic logs and estimates of thermal conductivities from Table 3 (Olmsted and others, 1975). Due to removal of moisture by evatranspiration, the upper 1 meter of material is assigned lower thermal conductivities which are listed in Table 4.

Table 3. Thermal conductivity values assigned to lithologic categories from driller logs
(All materials assumed to be saturated with water)

Lithologic category	Thermal conductivity (mcal cm^{-1} s^{-1} $^oC^{-1}$)
Unconsolidated Deposits	
Gravel; coarse gravel; clean gravel; gravel and sand; sandy gravel	5.0
Sand and gravel; gravelly sand	4.0
Sand and scattered gravel; coarse sand; sand; coarse sand with thin beds of clay and silt	3.5
Sand and silt; silty sand; fine sand	3.0
Silt, sand, and clay; sandy clay; clay and sand; silt; clay and gravel; clay, sand and gravel	2.5
Clay; silty clay; clay and silt	2.0
Semiconsolidated to Consolidated Deposits	
Cemented gravel; conglomerate	6.0
Cemented sand; sandstone; sandstone and siltstone; siltstone and sandstone	5.0
Claystone and siltstone; mudstone	4.5

Table 4. Thermal conductivity values assigned to lithologic categories in the depth range 0-1 m
(All materials assumed to be unsaturated)

Material	Thermal conductivity (x 10^{-3} cal cm^{-1} s^{-1} $^oC^{-1}$)
Clay	1.0
Silt; sand and clay	0.8
Silty sand; sand and silt	0.7
Sand	0.5

Several assumptions are made in the calculation of heat discharged by conduction. They are as follows (Olmsted and others, 1975):

1) All heat discharged from the thermal area is measured as conductive heat flow in the top 30 meters of material.

2) The thermal anomaly is defined by the isotherm at a depth of 30 meters.

3) The heat flow at any given point is equal to the thermal gradient computed from the temperature difference between the 30 m isotherm and the land surface, multiplied by the harmonic mean of the thermal conductivities of the horizontally stratified materials in the same depth range.

4) The mean annual surface temperature for the thermal area is equal to the mean annual air temperature.

5) The harmonic mean of the thermal conductivity of the material in each contoured temperature zone is equal to the average of the computed harmonic-mean conductivities found in each temperature zone.

The results obtained by this method are presented in Appendix III. The total heat discharge for the thermal area outlined in Plate 4 is 4.9×10^5 cal/sec (1.96 BTU/sec). If one assumes that an "average" home in Reno uses between 1200-1500 Therms/year (1 Therm = 100,000 BTU's) (Sierra Pacific Power Company) an estimate of the maximum number of users is possible. The results indicate that between 300 and 400 individual dwellings could at present make use of the thermal waters before heat extraction, for domestic heating, would exceed heat produced by the thermal system.

This "maximum permissible number of users" should be used with extreme caution. Data used in this calculation was obtained from available well logs, many of which are of questionable accuracy. The resulting maximum permissible number of users also assumes that all heat from the thermal area is put to use.

The method developed by Olmsted and others (1975) contains several assumptions not already mentioned. They assume that the thermal area is at equilibrium, import and export of heat are equal, and that the amount of energy supplying the thermal system is constant and will not vary. They also implied that all heat discharged can be removed for use. Therefore the method assumes that extraction of heat will have no effect upon the overall heat flow for the thermal system. In reality this is not the case.

There exists an analogy between extraction of heat from a thermal field and extraction of water from a well field. Equations for the description of heat conduction and flow of water through a porous medium have the same basic form. For heat flow the equation is:

$$H = -K \frac{dU}{dn}$$

where H equals heat flow, cal/sec, K is thermal conductivity, U equals temperature, N is distance over which heat flow takes place, and dU/dn is the thermal gradient.

The equation for flow of water through a porous medium is:

$$q = -K \frac{dh}{dL}$$

where q equals specific discharge, ft/day, K is hydraulic conductivity, h is head, L is distance along the flow path, and dh/dL equals the hydraulic gradient.

When a thermal well begins to extract heat, a heat sink, analogous to a cone of depression for a pumping well, develops. With increased extraction of heat, the heat sink would expand its area of influence. The heat sink would enlarge until it encompasses enough area so that heat extracted equals heat supplied by the thermal system. Around the zone of influence the thermal gradient would increase, thus more heat would flow to the area. Therefore, the total heat flow estimate arrived at by using Olmsted's (1975) method for Moana thermal system could be a conservative figure.

The assumption that all heat is discharged as conductive heat flow in the upper 30 m of material may also contribute significant error. It is assumed this depth or hinge point was derived at in an effort to eliminate temperature fluctuations in the upper few meters of material resulting from seasonal changes in air temperature. Depth of this hinge point will have a great effect upon the estimate of heat flow. If the point lies above 30 meters, heat flow estimate will be higher than the true value. This hinge point should be accurately known to obtain the best possible estimate for total heat flow.

Other sources of error may result from inaccurate well logs and in calculation of thermal conductivities especially when depth to water is great. In addition, the thermal gradients may not be accurate because of their modification by upward or downward convection or by boiling.

Currently there are approximately 30 individual dwellings, 2 motels and 1 apartment building using thermal waters to some extent. The author sees no loss of heat due to over-use in the near future. This is because of the high cost of heat system installations and limitation on

number of dwellings because of lot size. Conditions could change with future increases in home heating fuels resulting in a geothermal system being more economical for a larger number of families.

Plate 4 shows the thermal anomaly found 30 m below the land surface. This figure indicates the outline of the thermal area but by no extent the total area where hot water may be found. In section 22 T19N R19E a well was drilled for domestic heat and encountered 76°C water at a depth of 244 meters. In the early 1900's an exploratory oil well encountered "hot" water at a depth of 366 meters in section 21 T19N R19E. This tends to indicate that there is a great amount of thermal water at depth along the base of the Carson Range, with Moana being a near-surface discharge area for a portion of the thermal waters.

In the future, if the total number of users should near the conservative estimate of 300 to 400, further research should be started. Future work in the thermal area should include the drilling of 10 to 20 small diameter wells for a better estimate on the heat flow for the area. Another aspect of research should deal with proper spacing of thermal wells and the economics of multiple dwelling use of one large-diameter thermal well.

HEAT SOURCE

White (1964) calculated that Steamboat Springs produces approximately 3.7×10^{14} cal/yr, with an estimated flow of 5200 lpm. He considered that a magma body of granitic material, initially at 900°C, cooling to 500°C would release 175 cal/gram of material. With these assumptions White (1964) estimated that 0.0008 Km^3 per year of magma was needed to account for the Steamboat Springs thermal area. To explain the thermal anomaly for Truckee Meadows would require 0.001 Km^3 per year of a cooling magma body of granitic composition (White, 1964).

A problem arises when one considers the length of time thermal activity has been present in Truckee Meadows. White (1974) assigns Steamboat Springs thermal system an age of at least 100,000 years and more likely 3,000,000 years. This means a cooling magma body on the order of 1,000-30,000 Km^3 would be required to explain heat flow for this length of time.

A batholith, of granitic composition, intruded into the shallow crust, is not a satisfactory explanation for the heat source, unless one assumes that there either exists a fracture system within the cooling intrusive body to allow circulating water access to heat deeper in the magma body, or that heat is continually added to the magma from a larger source at depth.

Another alternative for explanation of the high thermal anomaly could be radioactive decay of one or more radioactive elements. This also appears to be unsatisfactory because surrounding country rock does not indicate the presence of large quantities of radioactive material

needed to account for the huge thermal anomaly. O'Connell (1975) conducted a complete analysis for radioactive elements in thermal waters found in Truckee Meadows. Results for various hot springs did not indicate the presence of large amounts of radioactive material (O'Connell, personal communication).

Faulting is another possible heat source for observed thermal areas in Truckee Meadows. There does exist a good correlation between thermal occurrences and areas exhibiting numerous faults. Large scale faulting could conceivably cause the release of heat resulting from friction during movement. This localized generation of energy could supply a portion or all heat required, depending upon the thermal system.

The author believes that faulting could supply heat for thermal systems in Truckee Meadows, though on a minor scale. It is possible that high correlation between faults and thermal areas could result from localization of thermal waters along faults.

Sass and others (1971) have established that Nevada is a region of greater than average heat flow. Hose and Taylor (1974) have related the thermal springs of northern Nevada to deep circulation of meteoric waters. They contend that (deeply circulating) meteoric waters move downward, along Basin and Range faults where deep circulating waters encounter high temperature rock, become heated and rise to the surface. They feel that the heat is derived from rock which is hot because of a high regional thermal gradient, the result of a high temperature upper mantle blanketed by a thin crust rather than from a still hot magma at some depth within the crust.

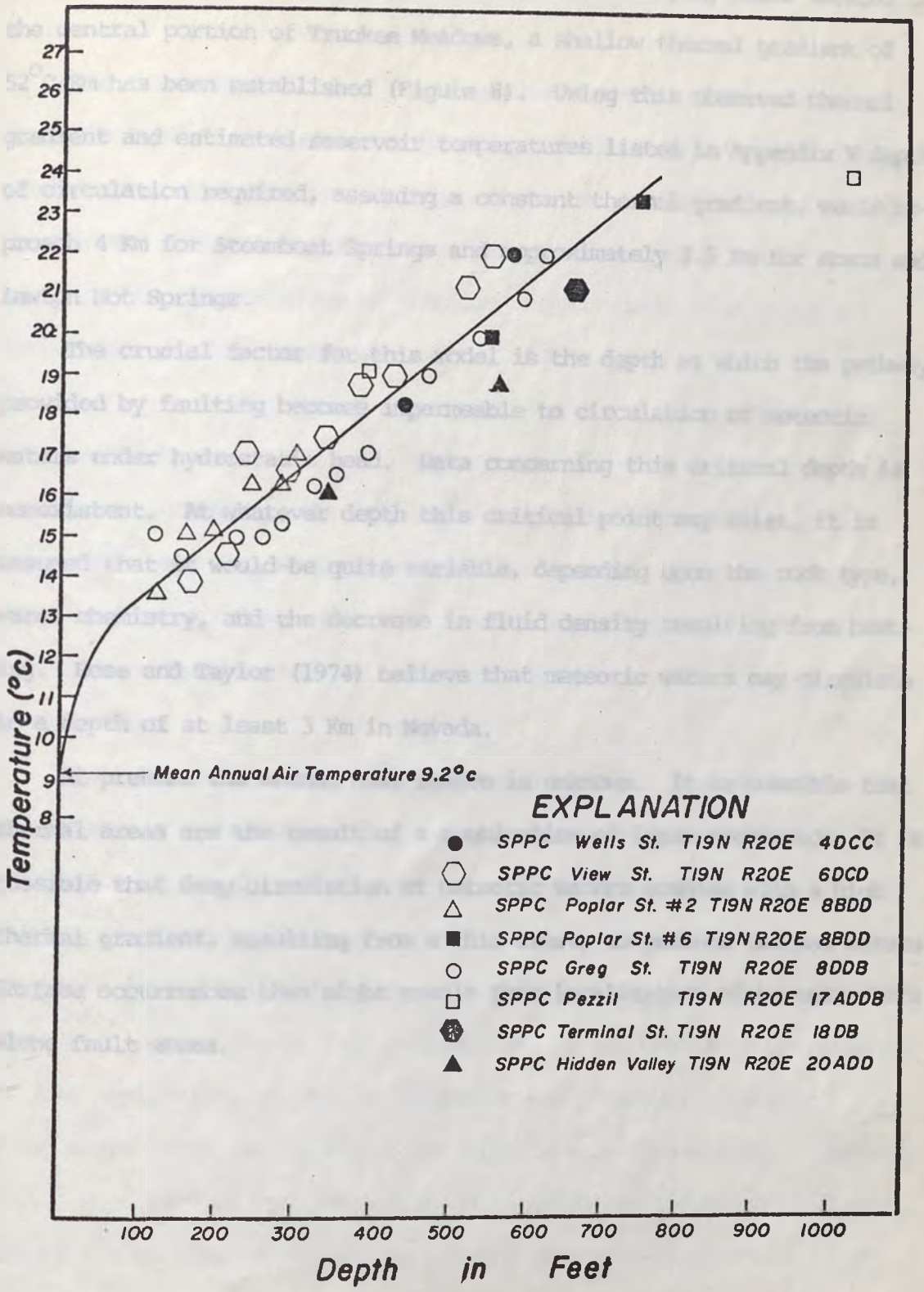

FIGURE 8. Thermal Gradient for Truckee Meadows

Based upon eight deep Sierra Pacific Power Company wells located in the central portion of Truckee Meadows, a shallow thermal gradient of 52°C/Km has been established (Figure 8). Using this observed thermal gradient and estimated reservoir temperatures listed in Appendix V depth of circulation required, assuming a constant thermal gradient, would approach 4 Km for Steamboat Springs and approximately 2.5 Km for Moana and Lawton Hot Springs.

The crucial factor for this model is the depth at which the pathway provided by faulting becomes impermeable to circulation of meteoric waters under hydrostatic head. Data concerning this critical depth is nonexistent. At whatever depth this critical point may exist, it is assumed that it would be quite variable, depending upon the rock type, water chemistry, and the decrease in fluid density resulting from heating. Hose and Taylor (1974) believe that meteoric waters may circulate to a depth of at least 3 Km in Nevada.

At present the actual heat source is unknown. It is possible that thermal areas are the result of a combination of ideas presented. It is possible that deep circulation of meteoric waters combine with a high thermal gradient, resulting from a thin crust, to produce thermal waters. Surface occurrences then might result from localization of heated waters along fault zones.

WATER CHEMISTRY

The chemical quality of the thermal and non-thermal ground-waters found in Truckee Meadows differ greatly. Table 5 shows analyses of ground-water from Steamboat Springs, Moana Hot Springs, Lawton Hot Springs and a Sierra Pacific Power Company water supply well. A wide range in the concentration of chemical constituents, both major and trace elements, is clearly shown.

Non-Thermal Water

The anions HCO_3^-, Cl^- and $SO_4^=$ along with the cations Na^+, K^+, Ca^{++}, Mg^{++}, and SiO_2 are the predominate dissolved ionic species. Table 5 shows average, range and percentage distribution of anionic and cationic species, based upon approximately 60 analyses of non-thermal ground-water.

The predominant ionic species found is HCO_3, a common component of all naturally occurring surface and ground-waters. Its concentration is a function of not only the bicarbonate added to the system but also of the pH, temperature and concentration of other dissolved solids. Observed Cl levels are believed to be derived principally from geothermal areas and to some extent from infiltration of surface water containing Cl from application of salt to sidewalks and highways. Bleached rock areas surrounding the basin are the major source area for SO_4 contribution. Abundance of various cations corresponds with what would be expected for an area consisting of volcanic and igneous material. High observed concentrations of Na and SiO_2 suggest mixing with geothermal

Table 5 Comparsion of Chemical Quality for Steamboat Springs, Moana, Lawton, and Non-thermal Ground Water.

Name.....	Spring 8, Steamboat		Well, Moana Hot Springs		Lawton Hot Springs		Well # 6 S.P.P.C.*	
Location....	T18N R20E 23 AB		T19N R19E 26 ADDD		T19N R18E 13 AC		T19N R20E 8 BDD	
Collection Date.....	Aug. 1949		March 1974		Feb. 1958		Aug. 1959	
	mg/l	epm	mg/l	epm	mg/l	epm	mg/l	epm
HCO_3.....	305.	5.00	85.	1.39	12.	0.16	116.	1.90
CO_3.....	0.	----	0.	----	20.	0.67	0.	----
Cl.....	865.	24.39	50.	1.41	57.	1.61	7.	0.20
SO_4.....	100.	2.08	457.	9.51	144.	3.00	57.	1.19
F.....	1.8	0.09	4.8	0.25	2.5	0.13	0.2	0.01
Br.....	0.2	----	0.1	----	----	----	----	----
I.....	0.1	----	0.2	----	----	----	----	----
H_2S.....	4.7	----	0.2	----	----	----	----	----
B.....	49.	----	2.0	----	1.3	----	----	----
Total Anions	1,326	31.6	599.	12.6	237.	5.57	180.	3.30
Na.....	653.	28.41	243.	10.58	117.	5.09	43.	1.87
K.....	71.	1.82	7.4	0.19	5.4	0.14		
Ca.....	5.0	0.25	23.	1.15	6.2	0.31	22.	1.10
Mg.....	0.8	0.06	0.2	0.02	0.1	0.01	3.9	0.32
Al.....	0.5	----	0.04	----	0.1	----	----	----
As.....	2.7	----	0.1	----	----	----	----	----
Fe.....	0.05	----	0.02	----	----	----	0.05	----
Hg.....	----	----	0.0005	----	----	----	----	----
Li.....	7.6	1.10	0.19	----	0.5	0.07	----	----
Mn.....	0.05	----	0.01	----	----	----	0.02	----
Sb.....	0.4	----	0.01	----	----	----	----	----
Se.....	----	----	0.005	----	----	----	----	----
Sr.....	0.5	----	0.5	----	----	----	----	----
Total Cation	742.	31.6	274.	11.9	129.	5.63	69.	3.3
SiO_2.....	293		102		46		39	
Sp. El. Con. (mhos/cm @ 25°C)	3210		1367		625		325	
TDS (sum)...	2361		975		354		288	
pH.....	7.9		8.3		9.0		8.0	
Depth (feet)	----		150		---		752	

* Sierra Pacific Power Company

waters.

The majority of trace elements present in non-thermal waters do not pose a significant health hazard. The species include Li, F, As, and B, all of which are found at low concentration levels and are believed to be derived from the thermal systems.

Figure 9 is a trilinear plot for major anions and cations found in non-thermal waters. Examination of the diagram shows two distinctly different influences. They are 1) mixing with waters having high concentrations of Cl and Na, and 2) mixing with waters high in SO_4 and Na. The first case is indicative of mixing with poor quality water derived from Steamboat Springs. High sulfate waters primarily occur near the margins of the valley. This is probably because most of the sulfate is derived from the hydrothermally altered bleached rock locations along the valley's margins. Sulfate concentrations generally decrease toward the central portion of the basin, which is attributed to mixing.

Thermal Waters

Forty-six chemical analyses of naturally occurring waters within Truckee Meadows are listed in Appendix VI. Table 7 lists average, range and average ionic ratio of the chemical constituents found in thermal waters.

Major ionic species are basically the same as those in non-thermal water with the exception of CO_3 being present in waters with an elevated pH. Significant differences do exist in the concentration and percentage of various ions. Chemical data from Table 5 adequately defines the average chemical quality of Steamboat Springs and Moana which are con-

Table 6 Average Chemical Quality of Non-thermal Ground Water, Truckee Meadows, Nevada

PARAMETER	AVERAGE VALUE	RANGE	AVERAGE IONIC RATIO (%)
Temperature (^{o}C)	14.7	9.4 - 19.4	-
pH	7.7	7.0 - 8.8	-
SEC (umhos/cm @ 25^{o}C)	609.	236. - 3780.	-
TDS (mg/l)	482.	117. - 3278.	-
HCO_3 (mg/l)	180.	68. - 435.	66.
Cl (mg/l)	23.	1.4 - 315.	9.
SO_4 (mg/l)	111.	2.4 - 1680.	25.
Na (mg/l)	51.	6.0 - 400.	34.
K (mg/l)	6.	1.0 - 39.	2.
Ca (mg/l)	48.	7.4 - 354.	40.
Mg (mg/l)	17.	3.0 - 137.	24.
SiO_2 (mg/l)	51.	15. - 101.	-

Table 7 Average Chemical Quality of Thermal Ground Water, Truckee Meadows, Nevada

PARAMETER	AVERAGE VALUE	RANGE	AVERAGE IONIC RATIO (%)
Temperature (^{o}C)	62.2	30. - 145.	-
pH	7.85	6.7 - 9.0	-
SEC (umhos/cm @ 25^{o}C)	1419.	194. - 3661.	-
TDS (mg/l)	1130.	162. - 3352.	-
HCO_3 (mg/l)	200.	78. - 461.	35.
CO_3 (mg/l)	6.2	0. - 104.	
Cl^3 (mg/l)	226.	2.6 - 999.	31.
SO_4 (mg/l)	245.	2.3 - 1959.	34.
Na (mg/l)	282.	5.8 - 770.	75.
K (mg/l)	24.	2.6 - 71.	
Ca (mg/l)	34.	1.4 - 336.	17.
Mg (mg/l)	10.	0.1 - 112.	8.
SiO_2 (mg/l)	121.	4.7 - 317.	-

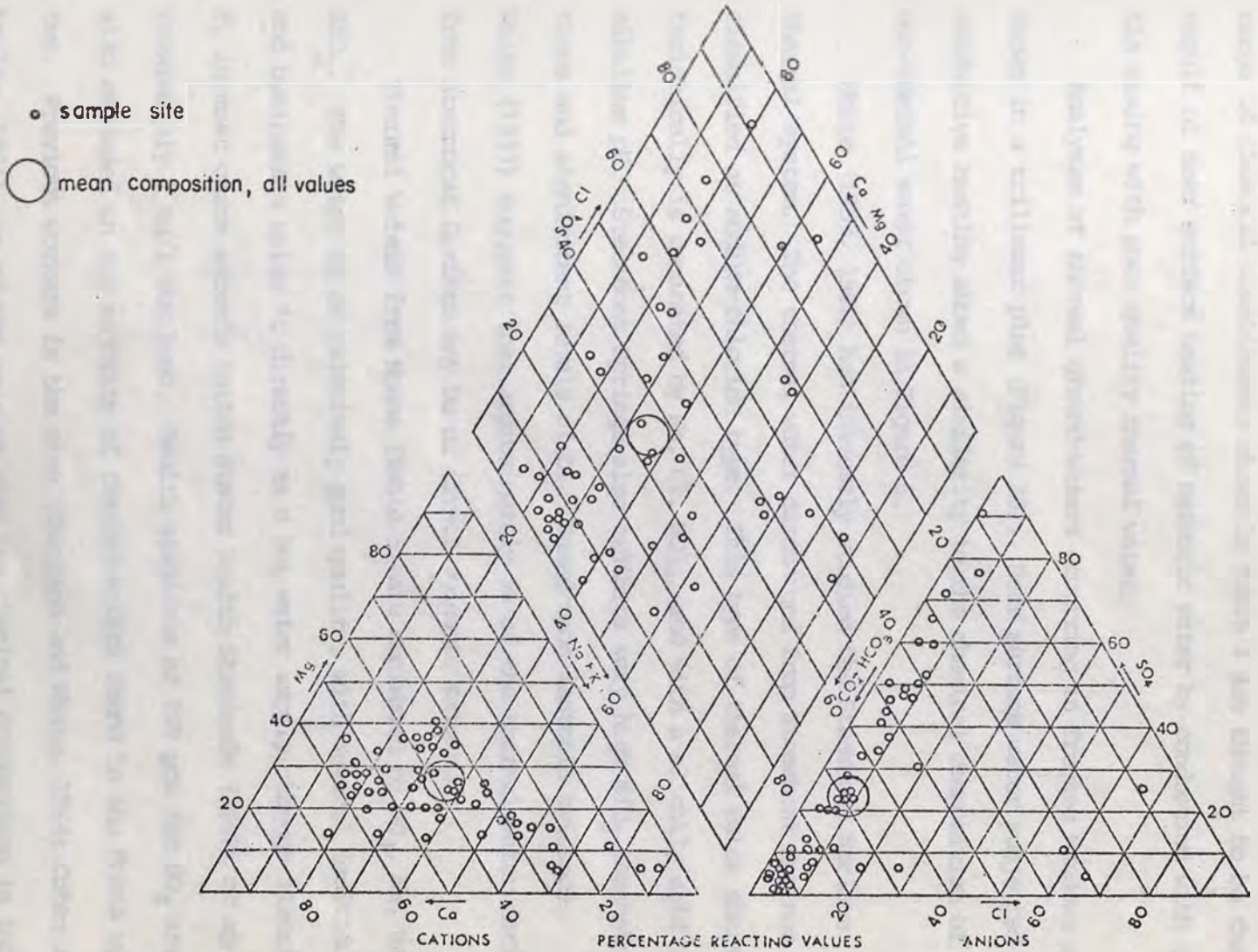

FIGURE 9. Trilinear Diagram of Non-thermal Waters for Truckee Meadows

sistent within the main thermal source areas before mixing takes place. Lack of data concerning Lawton Hot Springs makes it impossible to state that the listed chemical analysis is typical for the area. The lower range of chemical constituents shown in Table 1 are thought to be the result of near surface heating of meteoric water by conduction with little mixing with poor quality thermal water.

Analyses of thermal ground-waters occurring in Truckee Meadows are shown in a trilinear plot (Figure 10). Near surface water subjected to conductive heating shows a similarity to the chemical composition of non-thermal water shown in Figure 6.

White (1957, 1968) has intensely studied the Steamboat Springs thermal system. The thermal water discharged from Steamboat Springs is classified as sodium-chloride type. This type of thermal water charateristically is dominated by Na, Cl, HCO_3, and with a slightly acid to alkaline pH. Steamboat Springs also exhibits very high SiO_2 concentrations and significant levels of Li. Based upon isotopic evidence, White (1957) suggests that approximately 5% of the thermal water derived from Steamboat Springs may be of direct volcanic origin.

Thermal waters from Moana (Table 5) are dominated by SO_4, Na, and SiO_2. The water is of relatively good quality, with several individuals and businesses using it directly as a hot water supply, though fluoride, F, in most cases exceeds United States Health Standards (1962) of approximately 2 mg/l for Reno. Health standards of 250 ppm for SO_4 are also exceeded in the majority of thermal-waters found in the Moana system. Previous workers in the area (Thompson and White, 1964; Cohen and Loeltz, 1964) are of the opinion that the chemical composition is indic-

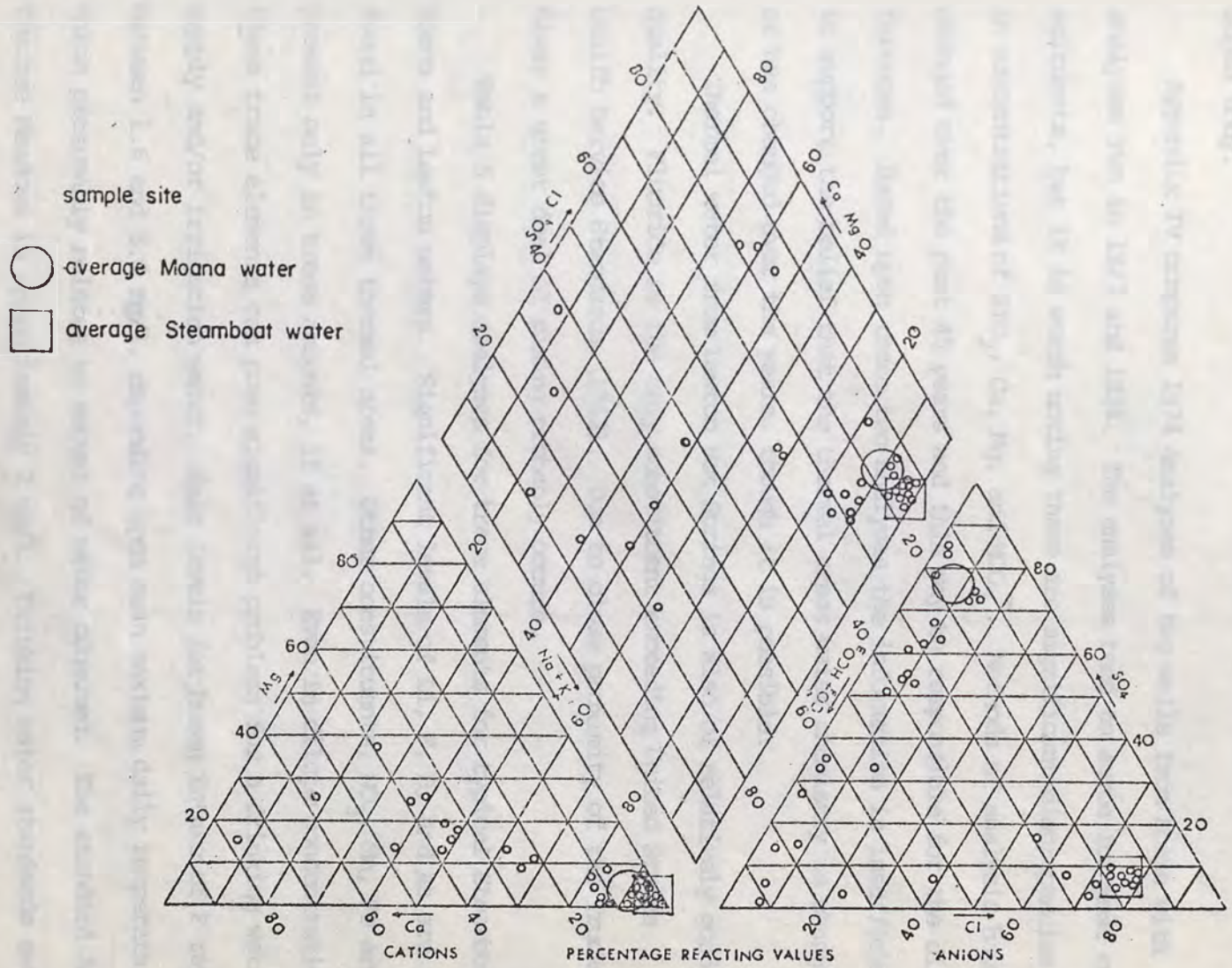

FIGURE 10. Trilinear Diagram of Thermal Waters for Truckee Meadows

ative of deep circulation with very little addition of magma derived fluids. The author agrees with the previous workers in that deep circulation takes place but feels that there are no fluids derived from a magma body.

Appendix IV compares 1974 analyses of two wells from Moana with analyses run in 1927 and 1928. The analyses tend to agree for most constituents, but it is worth noting there are significant discrepancies in concentrations of SiO_2, Ca, Mg, and HCO_3^-. Methods of analysis have changed over the past 45 years and this may be responsible for the differences. Based upon these two analyses the information is insufficient to support the belief that the thermal areas water chemistry is changing or has changed over the years, though it is possible.

Thermal water from Lawton Hot Springs is also of relatively good quality. Fluoride is the only constituent exceeding United States Health Service Standards (1962). Due to close proximity of the Truckee River a great deal of mixing probably occurs.

Table 5 displays analyses for trace elements for typical Steamboat, Moana and Lawton waters. Significant levels of Li, F, B, and As are found in all three thermal areas. Other constituents, NO_3, Mn, Fe are present only in trace amounts, if at all. Even in dilute concentrations these trace elements can pose significant problems for a drinking water supply and/or irrigation water. Safe levels for human intake of F range between 1.6 and 3.4 mg/l, depending upon mean maximum daily temperature, which presumably relates to amount of water consumed. The standard for Truckee Meadows is approximately 2 mg/l. Drinking water standards set by United States Public Health Service (1962) for As gives a maximum

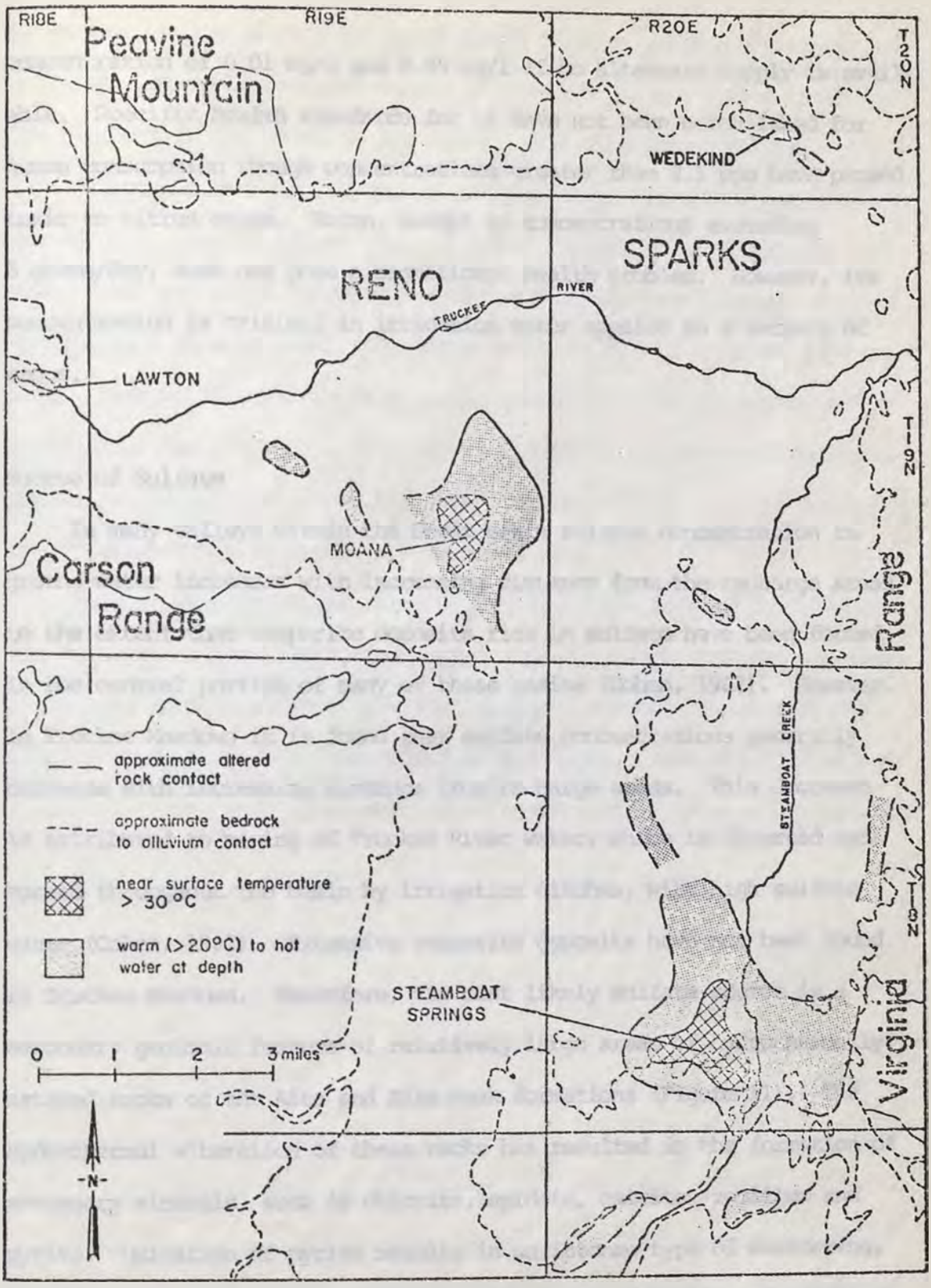

FIGURE 11. Location of Altered Rock Areas in Truckee Meadows

concentration of 0.01 mg/l and 0.05 mg/l if no alternate supply is available. Specific health standards for Li have not been established for human consumption though concentrations greater than 0.1 ppm have proved toxic to citrus crops. Boron, except in concentrations exceeding 5 grams/day, does not pose a significant health problem. However, its concentration is critical in irrigation water applied to a variety of crops.

Source of Sulfate

In many valleys within the Great Basin sulfate concentration in ground-water increases with increasing distance from the recharge areas to the extent that evaporite deposits rich in sulfate have been formed in the central portion of many of these basins (Cohen, 1962). However, in Truckee Meadows it is found that sulfate concentrations generally decrease with increasing distance from recharge areas. This decrease is attributed to mixing of Truckee River water, which is diverted and spread throughout the basin by irrigation ditches, with high sulfate water (Cohen, 1962). Extensive evaporite deposits have not been found in Truckee Meadows. Therefore, the most likely sulfate source is a secondary geologic feature of relatively large areas of hydrothermally altered rocks of the Alta and Kate Peak formations (Figure 11). The hydrothermal alteration of these rocks has resulted in the formation of secondary minerals, such as chlorite, epidote, calcite, zeolites and pyrite. Oxidation of pyrite results in an intense type of weathering, locally known as bleaching, which results in the formation of sulfurous and sulfuric acids which then bleach the altered rocks. Surface and

presumably subsurface runoff is typically high in sulfate and exhibits a low pH. These bleached zones are believed to be the source areas for the majority of SO_4 found in the thermal and cool ground-waters.

Figure 12 is a contour map of sulfate, $SO_4^=$, concentration in parts per million, for the Moana area. Sulfate concentration along with general water quality is depth dependent. Therefore, the diagram, excluding the main thermal area, only shows wells which are at least 100 meters deep. Many of these wells have perforations at different depths and water from these wells may be a mixture of water from several aquifers. Therefore, this figure should be used with caution but it does represent one interpretation of data which is available.

Sulfate concentrations shown in Figure 12 can be used to delinate the direction of ground-water movement from Moana Hot Springs. As thermal waters high in sulfate move down-gradient toward the basin center mixing occurs with surface waters low in sulfate. This mixing leads to a gradual decrease in observed sulfate concentration as shown in Figure 12.

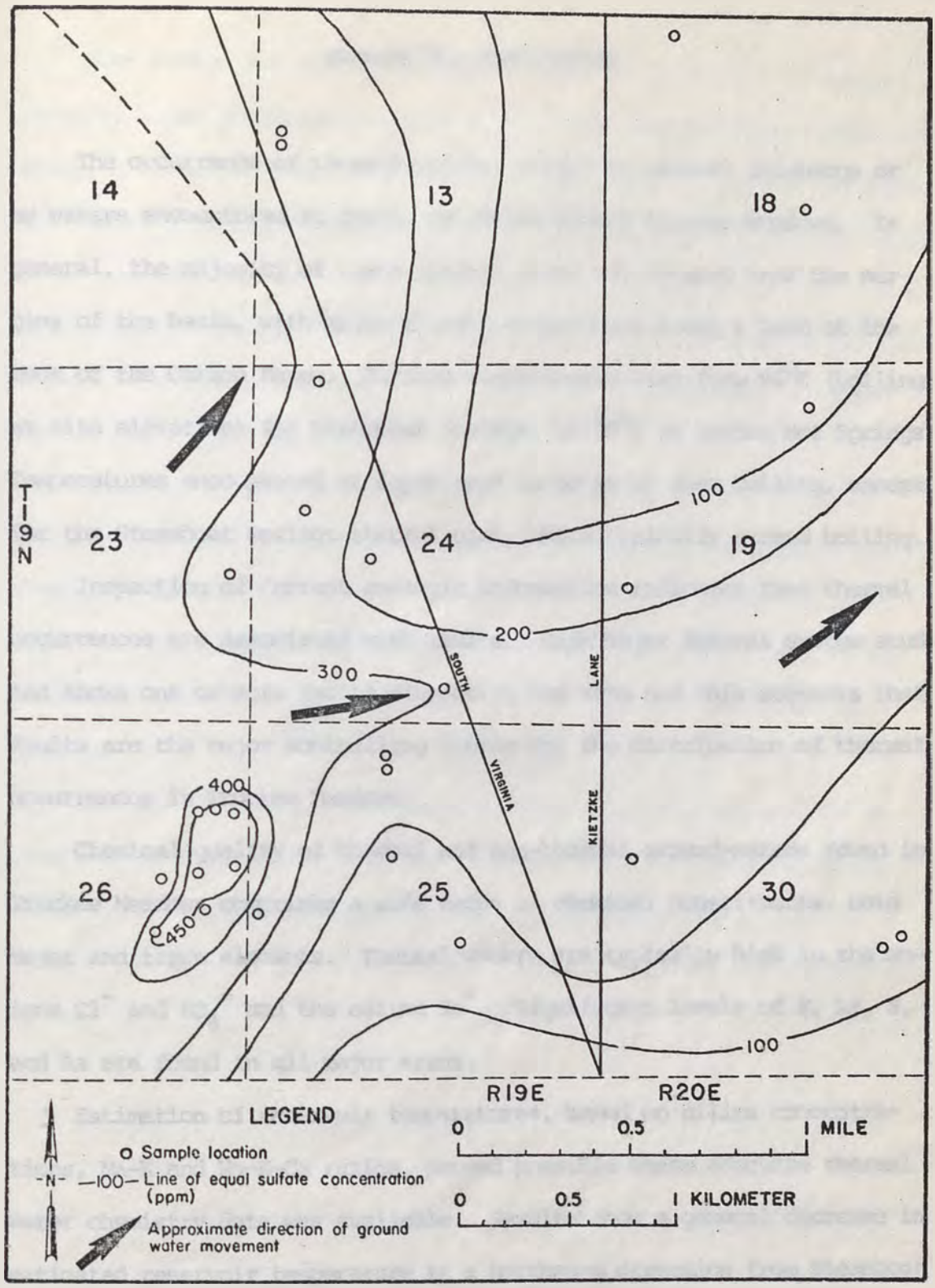

FIGURE 12. Contour Map of Sulfate Concentration for Moana Hot Springs

SUMMARY AND CONCLUSIONS

The occurrence of thermal waters, either by natural discharge or as waters encountered at depth, is common within Truckee Meadows. In general, the majority of these thermal areas are located near the margins of the basin, with major thermal occurrences along a band at the foot of the Carson Range. Surface temperatures vary from 96°C (boiling at site elevation) for Steamboat Springs, to 50°C at Lawton Hot Springs. Temperatures encountered at depth tend to be at or near boiling, except for the Steamboat Springs thermal area, which typically exceed boiling.

Inspection of current geologic information indicates that thermal occurrences are associated with faults. Each major thermal system studied shows one or more faults dissecting the area and this suggests that faults are the major controlling factor for the distribution of thermal occurrences in Truckee Meadows.

Chemical quality of thermal and non-thermal ground-waters found in Truckee Meadows comprises a wide range of chemical constituents, both major and trace elements. Thermal waters are typically high in the anions Cl^- and $SO_4^=$ and the cation Na^+. Significant levels of F, Li, B, and As are found in all major areas.

Estimation of reservoir temperatures, based on silica concentrations, Na-K and Na-K-Ca ratios, proved possible where adequate thermal water chemistry data was available. Results show a general decrease in estimated reservoir temperature in a northward direction from Steamboat Springs. Estimated temperatures are 201°C for Steamboat, 134°C for Moana and 130°C for Lawton.

Heat source for thermal occurrences may be the result of several factors. High temperatures at depth have been attributed to radioactive decay, a hot magma body, faulting and a high regional thermal gradient, the result of a high temperature upper mantle blanketed by a thin crust. It is possible that deep circulation of meteoric waters combine with a high thermal gradient, resulting from a thin crust, to produce thermal waters. Surface occurrences then result from localization of heated waters along fault zones.

Based upon eight Sierra Pacific Power Company wells, a shallow thermal gradient of $52^{o}C/Km$ has been established for Truckee Meadows. Extrapolation of this thermal gradient and estimated temperatures at depth for the main thermal areas gives circulation depths of 4 Km for Steamboat Springs and approximately 2.5 Km for Moana and Lawton Hot Springs.

With available data the heat discharge for Moana Hot Springs is estimated to be 4.9×10^{5} cal/sec (1.96 BTU/sec). Assuming a steady state system exists for Moana Hot Springs, a conservative estimate of between 300 and 400 individual dwellings could make use of the thermal waters.

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APPENDIX I

Enthalpies of Liquid Water and Quartz Solubilities at Selected Temperatures

Temperature °C	Enthalpy cal./gm.	Silica ppm
50	50.0	13.5
75	75.0	26.6
100	100.1	48
125	125.4	80
150	151.0	125
175	177.0	185
200	203.6	265
225	230.9	365
250	259.2	486
275	289.0	614
300	321.0	692

APPENDIX II

Values of X_t and X_{Si} at Various Assumed Temperatures of the Hot Water Component for Lawton Hot Springs

Temperature of hot water, °C	Warm Spring, t = 49°C Warm Spring, SiO_2 = 46 ppm	
	X_t	X_{Si}
50	.0245	----
75	.395	----
100	.562	.087
125	.656	.618
150	.717	.79
175	.76	.869
200	.79	.91
225	.816	.94

$$X_t = \frac{X - \text{Spring Temperature } ^\circ C}{X - \text{Mean Annual Air Temperature}}$$

$$X_{Si} = \frac{X - SiO_2 \text{ Concentration of Hot Spring}}{X - SiO_2 \text{ Concentration of Non-thermal Ground Water}}$$

130°C = Estimated Maximum Temperature

.67 = Estimated Fraction of Cold Water Mixed

APPENDIX III

Estimate of Conductive Heat Discharge from Moana Hot Springs Thermal Area

Temperature Range ^{o}C	Thermal Gradient ($\times 10^{-3}$ ^{o}C/cm)	Heat Flow ($\times 10^{-6}$ cal/cm^2 sec)	Area ($\times 10^{9}$ cm^2)	Heat Discharge ($\times 10^{5}$ cal/sec)
20-40	2.63	7.52	37.15	2.79
40-60	5.75	13.50	9.61	1.30
60-80	8.38	17.60	2.48	0.44
80	20.6	44.91	0.90	0.41
Totals			50.14	4.94

4.93×10^{5} cal/sec = 1.55×10^{13} cal/yr

1 BTU = 252 calories

Average home uses 1.2×10^{8} BTU/yr to 1.5×10^{8} BTU/yr

APPENDIX IV

Comparison of Water Analyses for Moana Hot Springs Thermal Area

Location	T19N R19E 26 DACB		T19N R19E 26 ADAB	
Date of Analysis	1927	1974	1928	1974
pH	----	7.95	----	7.78
TDS (sum)	1007.	969.	1176.	1017.
EC	----	1345.	----	1430.
HCO_3^-	98.	85.8	148.	99.
Cl^-	54.	48.3	56.	53.
$SO_4^=$	477.	454.6	512.	478.2
Na^+	223.	235.6	303.	258.7
K^+	*	7.98	1.86	7.17
Ca^{++}	40.	23.0	34.7	22.1
Mg^{++}	12.	0.09	0.65	0.79
SiO_2	130.	106.	120.3	92.3

* Potassium reported with Sodium

APPENDIX V

Observed and Estimated Temperatures for Steamboat Springs, Moana and Lawton Hot Springs

	Steamboat	Moana	Lawton
Observed Temperature (^{o}C)	94	90	49
Na/K	180	107	137
Na/K + 1/3 Ca/Na	208	129	147
Na/K + 4/3 Ca/Na	233	97	109
Silica-Adiabatic	186	134	99
Silica-Heat Conduction	201	139	98

APPENDIX VI

Chemical Analyses of Thermal Ground Waters, Truckee Meadows, Nevada

Location	Source	Depth (feet)	Date of Collection	Analyst	Temp. (°C)	Bicarbonate mg/l	Bicarbonate epm	Carbonate mg/l	Carbonate epm	Chloride mg/l	Chloride epm	Sulfate mg/l	Sulfate epm	Sodium mg/l	Sodium epm
18N 20E 9BD	Well	122	05-08-56	USBR	30	227	3.721	—	—	313	8.827	50	1.041	262	11.397
18N 20E 17DC	Spring	—	01-14-58	USGS	34.5	224	3.671	—	—	94	2.651	17	.354	130	5.655
18N 20E 17DC	Well	99	10-22-48	NSHD	45.5	461	7.556	—	—	82	2.312	10	.208	115	5.002
18N 20E 23BC	Well	—	—	DRI	41	306	5.015	—	—	337	9.503	147	3.061	318	13.833
18N 20E 27B	Well	115	11-02-72	NSHD	48.9	388	6.359	12	.400	950	26.790	75	1.561	762	33.147
18N 20E 27DDD	Well	—	08-25-59	NSHD	40	158	2.590	—	—	7	.197	504	10.493	112	4.872
18N 20E 28BA	Well	151	06-03-58	USGS	121	172	2.819	65	2.166	836	23.575	130	2.707	660	28.710
18N 20E 28BDC	Well	—	08-02-60	NSHD	75	256	4.196	—	—	805	22.701	130	2.707	630	27.405
18N 20E 28CB	Well	200	01-05-50	USGS	145	337	5.523	—	—	836	23.575	94	1.957	640	27.840
18N 20E 29BC	Well	82	06-49	USGS	34	78	1.278	—	—	2.6	.073	11	.229	12	.522
18N 20E 33AB	Well	—	09-28-68	DRI	52	300	4.917	46	1.533	999	28.172	121	2.159	770	33.495
18N 20E 33AB	Spring	—	08-49	USGS	89	305	4.999	—	—	865	24.393	100	2.082	653	28.405
18N 20E 33BA	Spring	—	07-45	USGS	95	292	4.786	20	.667	949	26.762	129	2.686	707	30.754
18N 20E 33BD	Spring	—	02-05-57	USGS	58	328	5.376	—	—	790	22.278	142	2.956	644	28.014
18N 20E 33CA	Spring	—	07-45	USGS	57	419	6.867	—	—	752	21.206	106	2.207	602	26.187
18N 20E 33DBA	Spring	—	08-27-68	DRI	54	336	5.507	—	—	767	21.269	141	2.936	635	27.622
18N 20E 33DB	Well	—	—	USGS	92	191	3.130	104	3.466	747	21.065	105	2.186	605	26.317
18N 20E 33DC	Well	258	—	—	75	146	2.393	19	.633	8.4	.237	2.3	.048	69	3.001
18N 20E 34C	Well	—	02-22-63	NSHD	70	242	3.966	—	—	6	.169	72	1.499	18	.783
18N 20E 34CAA	Well	—	01-07-63	NSHD	66	158	2.590	—	—	5	.141	72	1.499	5.8	.252
18N 20E 34DA	Well	—	—	NSHD	50	95	1.557	—	—	6	.169	480	9.994	101	4.393
19N 18E 13AC	Spring	—	02-11-58	USGS	49	12	.197	20	.667	57	1.607	144	2.998	117	5.089
19N 19E 22CD	Well	270	08-08-46	NSHD	30	378	6.195	—	—	26	.733	1959	40.786	500	21.750
19N 19E 23DA	Well	103	05-20-58	USGS	37	211	3.548	—	—	32	.902	325	6.766	199	8.656
19N 19E 13BC	Well	785	—	—	30	193	3.163	—	—	30	.846	258	5.372	148	6.438
19N 19E 24BBA	Well	900	—	DRI	42	131	2.147	—	—	31	.874	258.3	5.378	175	7.612
19N 19E 24CABA	Well	—	—	DRI	47.2	135.9	2.227	—	—	20.2	.570	170.6	3.552	139	6.046
19N 19E 24BCDB	Well	1006	—	DRI	59	143.6	2.356	—	—	26	.282	226.7	4.720	154.7	6.731
19N 19E 24DDC	Well	—	01-18-58	NSHD	48	119	1.950	—	—	31	.874	294	6.121	181.6	7.90
19N 19E 25BA	Well	67	—	—	36	165	2.704	—	—	16	.451	153	3.185	130	5.655
19N 19E 25BA	Well	700	02-11-58	USGS	45.5	134	2.196	—	—	24	.677	221	4.601	150	6.525
19N 19E 25BD	Well	77	04-74	DRI	33.5	159	2.606	—	—	17.3	.488	155.9	3.245	127.49	5.546
19N 19E 25BD	Well	95	07-09-47	NSHD	44.5	139	2.278	17	.567	32	.902	225	4.684	126	5.568
19N 19E 25CBBB	Well	225	—	DRI	63.1	131.5	2.156	—	—	33.5	.945	304.6	6.343	189.35	8.237
19N 19E 26ADAA	Well	247	—	DRI	84.2	107.68	1.765	—	—	54	1.523	462.8	9.635	266.2	11.581
19N 19E 26ADAB	Well	245	—	DRI	85	97.55	1.599	—	—	54	1.523	448.8	9.345	243.2	10.579
19N 19E 26ADA	Well	464	—	DRI	85	99	1.629	—	—	53	1.495	478.2	9.957	256.74	11.255
19N 19E 26ADCC	Well	230	—	DRI	90	146	2.472	—	—	42	1.184	348.3	7.252	203	8.832
19N 19E 26ADDA	Well	510	—	DRI	78	100.6	1.649	—	—	53	1.495	465.5	9.692	293	12.746
19N 19E 26ADDD	Well	150	—	DRI	89.9	86.2	1.413	—	—	50	1.410	457	9.514	243.19	10.579
19N 19E 26DACB	Well	150	—	DRI	85	85.8	1.407	—	—	48.3	1.362	454.6	9.465	235.64	10.250
19N 19E 26DABA	Well	198	02-18-74	DRI	80	95	1.557	—	—	53	1.495	419	8.724	246	10.788
19N 19E 26DC	Well	750	10-25-39	NSHD	82	88	1.442	—	—	52	1.466	478	9.952	241	10.483
20N 19E 23C	Well	—	02-05-58	NSHD	60	237	3.884	—	—	28	.790	271	5.642	—	—
20N 19E 23C	Well	—	02-05-58	NSHD	60	160	2.622	—	—	7.50	.212	126	2.623	—	—
20N 20E 27C	Well	—	08-28-60	NSHD	45	205	3.360	—	—	27	.761	110	2.290	77.03	3.351

CLHT = Curtis Laboratories, Houston, Texas
DRI = Desert Research Institute-CWRR
NSHD = Nevada State Health Division
USBR = U.S. Bureau of Reclamation
USGS = U.S. Geological Survey

APPENDIX VI (Continued)

Location	Potassium mg/l	Potassium epm	Calcium mg/l	Calcium epm	Magnesium mg/l	Magnesium epm	Silica mg/l	Arsenic mg/l	Boron mg/l	Fluoride mg/l	Lithium mg/l	Total Dissolved Solids (sum of mg/l)	Specific Conductance (umhos/cm @ 25°C)	pH
18N 20E 9BD	7.4	.189	19	.948	12	.987	115	—	12.3	.3	—	1032	1508	7.9
18N 20E 17DC	15	.384	9.3	.464	2.1	.173	134	—	—	.5	.4	632	729	7.6
18N 20E 17DC	•		72	3.593	18	1.480	23	—	5	—	—	*786	623	7.57
18N 20E 23BC	27	.691	44	2.196	12.4	1.020	152	.28	22.1	—	—	1367	1837	7.1
18N 20E 27B	•		30	1.497	3	.247	—	.64	—	—	—	2230	—	8.27
18N 20E 27DDD	•		98	4.890	43	3.536	—	—	—	—	—	927	—	7.3
18N 20E 28BA	68	1.739	1.4	.070	.0	.000	121	—	17	2.5	10	2086	3360	8.7
18N 20E 28BDC	•		27	1.347	11	.905	—	—	—	1.55	—	1862	—	7.05
18N 20E 28CB	64	27.840	11	.549	1.0	.082	299	—	46	2.1	7.6	2338	3150	7.6
18N 20E 29BC	5	.128	15	.748	2.8	.230	36	—	—	—	—	162	194	7.65
18N 20E 33AB	60	1.535	2.3	.115	.4	.033	235	—	—	2.6	—	2536	3661	8.7
18N 20E 33AB	71	1.816	5	.249	.8	.066	293	2.7	49	1.8	7.6	2354	—	7.9
18N 20E 33BA	75	1.918	12	.599	.5	.041	317	1.3	30	2.2	7	2542	—	8.2
18N 20E 33BD	59	1.509	14	.699	1.9	.156	205	—	2.2	2.2	—	2148	3240	6.7
18N 20E 33CA	54	1.381	23	1.148	2.0	.164	205	4	25	1.6	6	2196	—	7.7
18N 20E 33DBA	65	1.663	25	1.247	.6	.049	245	—	58	2.2	—	2275	2933	7.05
18N 20E 33DB	56	1.432	3.9	.195	.5	.041	222	.4	24	1.8	6	2066	—	8.6
18N 20E 33DC	6.8	.174	2.0	.100	.4	.033	4.7	—	.1	—	—	182	348	9.0
18N 20E 34C	•		67	3.343	18	1.480	—	—	—	—	—	423	—	7.22
18N 20E 34CAA	•		66	3.293	8.8	.724	—	—	—	—	—	316	—	7.81
18N 20E 34DA	•		78	3.892	40	3.290	—	—	—	.5	—	806	—	7.75
19N 18E 13AC	5.4	.138	6.2	.309	.1	.008	46	—	1.3	2.5	.5	412	625	9.0
19N 19E 22CD	—	—	336	16.766	112	9.211	41	—	—	.4	—	3352	—	—
19N 19E 23DA	3.7	.095	21	1.048	4.1	.337	79	—	.74	1.5	.8	879	1210	7.9
19N 19E 13BC	•		39	1.946	12	.987	55	—	—	—	—	735	—	—
19N 19E 24BBA	5.96	.152	15.8	.788	1.49	.123	57.8	.13	.75	.75	.12	679	942	7.95
19N 19E 24CABA	7.38	.189	5.20	.259	.30	.025	85.4	.10	.76	.81	.17	567	724	8.06
19N 19E 24BCDB	6.55	.168	5.68	.283	.40	.033	85.8	.01	.6	.5	.18	650	886	7.76
19N 19E 24DDC	•		19.2	.958	.97	.080	—	—	—	—	—	646	—	7.39
19N 19E 25BA	2.6	.067	16	.798	.7	.058	97	—	—	4.5	.8	586	697	8.0
19N 19E 25BA	8.2	.210	15	.748	.1	.008	86	—	—	2.1	.7	641	792	7.9
19N 19E 25BD	5.50	.141	12.14	.606	1.04	.085	50	.04	.882	2.9	.07	532	725	8.13
19N 19E 25BD	•		38	1.896	10	.822	27	—	—	—	—	616	—	—
19N 19E 25CBBB	5.50	.141	16.5	.824	.405	.033	92.6	.11	1.36	4.18	.14	780	1035	8.05
19N 19E 26ADAA	7.57	.194	13.08	.653	.255	.021	114	.06	2.08	5.1	.19	1033	1454	8.28
19N 19E 26ADAB	7.71	.197	14.23	.710	.19	.016	111	.01	1.87	5.1	.19	984	1423	8.35
19N 19E 26ADA	7.17	.183	22.1	1.103	.79	.065	92.3	.11	2.08	4.8	.18	1012	1430	7.78
19N 19E 26ADCC	7.37	.188	28.98	1.446	.786	.065	134.7	.04	1.80	4.8	.16	918	1185	7.65
19N 19E 26ADDA	8.1	.207	25	1.247	.26	.021	103.2	.20	1.77	6.3	—	1057	1320	8.2
19N 19E 26ADDD	7.36	.188	23.4	1.166	.205	.017	102	.10	1.99	4.83	.19	975	1367	8.29
19N 19E 26DACB	7.98	.204	23	1.148	.085	.007	106	.11	1.94	5.15	.19	969	1345	7.95
19N 19E 26DABA	7.1	.182	20.5	1.028	.32	.026	103.7	.09	1.74	4.95	.22	959	1070	7.50
19N 19E 26DC	•		33	1.647	9.0	.740	95	—	—	—	—	996	1327	7.9
20N 19E 23C	—	—	89.7	4.476	58.2	4.786	—	—	—	—	—	NA	—	—
20N 19E 23C	—	—	49.60	2.475	25.30	2.081	—	—	—	—	—	NA	—	—
20N 20E 27C	•		54.46	2.718	12.65	1.040	—	—	—	—	—	486	—	7.72

*Difference between anions and cations, in epm, assumed to be sodium and potassium and calculated as sodium.

Tr = Trace

APPENDIX VII

Chemical Analyses of Non-thermal Ground Waters, Truckee Meadows, Nevada

Location	Source	Depth (feet)	Date of Collection	Analyst	Temp (°C)	Bicarbonate mg/l	Bicarbonate epm	Carbonate mg/l	Carbonate epm	Chloride mg/l	Chloride epm	Sulfate mg/l	Sulfate epm	Sodium mg/l	Sodium epm
17N 20E 7D	Well	107	—	NSHD	24	151	2.475	—	—	5	.141	3	.062	19	.826
18N 20E 6AB	Well	504	08-20-68	CLHT	21.7	154	2.524	—	—	2	.056	18	.375	45	1.958
18N 20E 9CA	Well	45	05-08-56	USBR	22.2	151	2.475	9	.300	128	3.610	30	.625	147	6.394
18N 20E 9CC	Well	84	05-19-58	USGS	26.7	224	3.671	—	—	160	4.512	17	.354	160	6.960
18N 20E 14B	Well	103	07-24-73	NSHD	22.2	268	4.393	—	—	490	13.818	143	2.977	330	14.355
18N 20E 14BB	Well	—	05-14-58	USGS	23.9	264	4.327	—	—	511	14.410	151	3.144	313	13.615
18N 20E 14BC	Well	48	05-14-58	USGS	21.7	258	4.229	—	—	360	10.152	125	2.602	202	8.787
18N 20E 17AD	Well	73	05-08-56	USBR	22.2	176	2.885	9.6	.320	6.0	.169	6.2	.129	79	3.436
18N 20E 17AD	Well	100	05-08-56	USBR	29.4	228	3.737	6.6	.220	12	.338	7.6	.158	94	4.089
18N 20E 20DD	Well	66	02-11-46	NSHD	23.5	102	1.672	—	—	14	.395	21	.437	4	.174
18N 20E 21CA	Well	44	05-19-58	USGS	21	126	2.065	—	—	6.0	.169	5.8	.121	22	.957
18N 20E 27DC	Well	195	03-29-59	USGS	29.4	148	2.426	—	—	6.2	.175	508	10.577	100	4.350
18N 20E 28AB	Well	80	05-14-58	USGS	22.2	241	3.950	—	—	73	2.059	22	.458	83	3.610
18N 20E 29B	Well	160	07-30-71	NSHD	23.3	212	3.475	—	—	6	.169	13	.271	18	.783
18N 20E 30CD	Well	300	02-11-58	USGS	20	162	2.655	—	—	2.9	.082	2.4	.050	22	.957
18N 20E 34	Well	126	04-17-72	NSHD	29.4	361	5.917	—	—	750	21.150	234	4.872	679	29.537
18N 20E 34BB	Well	225	06-11-73	NSHD	27.8	200	3.278	—	—	43	1.213	543	11.305	230	10.005
19N 19E 4DCC	Well	582	08-09-60	—	22	110	1.803	12	.400	8	.226	84	1.749	55	2.392
19N 19E 22AC	Well	184	02-13-58	USGS	23.3	156	2.557	—	—	22	.620	48	.999	23	1.000
19N 19E 36BAA	Well	—	06-04-62	NSHD	28	185	3.032	—	—	11	.310	28.8	.60	57.75	2.512
19N 20E 6DCD	Well	550	10-12-68	—	22	128	2.098	—	—	4	.113	98	2.040	35	1.522
19N 20E 8AD	Well	451	01-14-58	USGS	20	106	1.737	—	—	3.1	.087	59	1.228	48	2.088
19N 20E 8BDD	Well	752	08-24-59	—	23.3	116	1.901	—	—	7	.197	57	1.187	43	1.870
19N 20E 8DDB	Well	621	11-21-66	—	22	165	2.704	—	—	8	.226	149	3.102	126	5.481
19N 20E 17ADDB	Well	1025	08-04-59	CLHT	24	200	3.278	—	—	21	.592	204	4.247	157	6.829
19N 20E 18BBA	Well	660	05-22-59	CLHT	21.2	104	1.705	—	—	5	.141	70	1.457	69	3.001
19N 20E 18DB	Well	685	08-27-60	CLHT	21.2	122	2.000	—	—	5	.141	78	1.624	79.5	3.471
19N 20E 27AC	Well	650	01-13-58	USGS	22	241	3.950	—	—	264	7.445	225	4.685	160	6.960
19N 20E 30BC	Well	600	01-13-58	USGS	24	116	1.901	—	—	30	.846	280	5.380	170	7.395
19N 20E 30DA	Well	826	03-01-62	CLHT	20	168	2.754	—	—	14	.395	121	2.519	107	4.654
17N 20E 8	Well	102	10-02-72	NSHD	13.9	156	2.557	—	—	4.0	.113	7.0	.146	21	914
17N 20E 9	Well	115	03-26-73	NSHD	9.4	181	2.967	—	—	4.0	.113	13.0	.271	32	1.392
18N 19E 1	Well	170	07-03-73	NSHD	11.1	193	3.163	—	—	11	.310	19	.396	29	1.261
18N 19E 7	Well	120	10-06-71	NSHD	14.4	124	2.032	—	—	3	.085	3	.062	9	392
18N 19E 10AA	Spring	—	01-14-58	USGS	15.6	138	2.262	—	—	3	.085	6.4	.133	19	826
18N 19E 12AD	Well	135	06-03-58	USGS	15	164	2.688	—	—	7.1	.200	8.8	.183	14	609
18N 19E 12CB	Well	240	01-14-58	USGS	15	222	3.639	—	—	4.0	.113	8.4	.175	19	.826
18N 20E 3BC	Well	107	05-11-56	USBR	12.8	255	4.179	—	—	282	7.952	66	1.374	163	7.090
18N 20E 6DB	Well	—	05-08-56	USBR	17.2	139	2.278	8.1	.270	3.6	.102	3.4	.071	14	609
18N 20E 8AC	Well	200	05-11-56	USBR	17.8	115	1.885	12	.400	2.4	.068	2.9	.060	12	.522
18N 20E 8BB	Well	20	05-13-58	USGS	17.2	183	2.999	—	—	1.5	.042	4.1	.085	14	.609
18N 20E 17	Well	46	08-10-72	NSHD	12.8	68	1.115	—	—	5.0	.141	7.0	.146	6	.261
18N 20E 18	Well	14	02-12-73	NSHD	15	144	2.360	—	—	1.0	.028	4	083	9	.392
18N 20E 20BB	Well	107	06-03-58	USGS	13.9	164	2.688	—	—	3.5	.099	4.4	.092	16	.696
18N 20E 29	Well	78	01-10-73	NSHD	14.4	232	3.802	—	—	5.0	.141	14	.291	28	1.218

APPENDIX VII (Continued)

Location	Potassium mg/l	Potassium epm	Calcium mg/l	Calcium epm	Magnesium mg/l	Magnesium epm	Silica mg/l	Arsenic mg/l	Boron mg/l	Fluoride mg/l	Lithium mg/l	Total Dissolved Solids (sum of mg/l)	Specific Conductance (umhos/cm @ 25°C)	pH
17N 20E 7D	•		24	1.198	9	.740	—	—	—	—	—	211	—	7.97
18N 20E 6AB	•		14	.699	4	.329	62	—	—	.2	—	299	213	7.88
18N 20E 9CA	13	.333	3	.150	2.2	.181	111	—	8.2	.4	—	603	752	8.5
18N 20E 9CC	14	.358	10	.499	4.6	.378	102	—	.61	3	3.1	696	969	7.5
18N 20E 14B	28	.716	73	3.643	23	1.892	—	—	—	.21	—	1359	—	7.13
18N 20E 14BB	31	.793	63	3.144	46	3.783	113	—	.44	.3	4.4	1497	2320	7.5
18N 20E 14BC	24	.614	68	3.393	43	3.536	79	—	.66	.2	3.1	1163	1810	7.2
18N 20E 17AD	5.9	.151	3.8	.190	.4	.033	96	—	.88	1.0	—	385	369	8.4
18N 20E 17AD	9.4	.240	3.0	.150	2.7	.222	109	—	2.1	..7	—	490	457	8.3
18N 20E 20DD	•		27	1.347	8	.658	25	—	—	—	—	201	—	—
18N 20E 21CA	5.7	.146	19	.948	4.6	.378	79	—	.05	.1	.6	278	255	7.1
18N 20E 27DC	5.8	.148	114	5.689	36	2.961	38	—	.06	.1	—	957	1200	7.6
18N 20E 28AB	6.6	.169	34	1.697	9.2	.757	61	—	.03	.2	1.1	536	671	7.6
18N 20E 29B	•		51	2.545	10	.822	—	—	—	—	—	310	—	8.04
18N 20E 30CD	2.5	.064	26	1.297	4.9	.403	29	—	.05	—	.3	256	267	7.4
18N 20E 34	•		32	1.597	8	.658	—	.005	—	1.24	—	2056	—	7.69
18N 20E 34BB	19	.486	64	3.194	16	1.316	—	.03	—	—	—	1117	—	7.23
19N 19E 4DCC	•		26	1.297	6.2	.510	32	—	—	.2	—	333	—	8.6
19N 19E 22AC	2.6	.067	51	2.545	7.1	.584	41	—	—	.4	.4	351	436	8.1
19N 19E 36BAA	•		20.82	1.039	5.85	.481	—	—	—	—	—	309	—	7.30
19N 20E 6DCD	•		38	1.896	12	.987	56	—	—	.6	—	379	410	7.94
19N 20E 8AD	9.4	.240	11	.549	2.9	.238	73	—	—	.2	.3	314	331	7.8
19N 20E 8BDD	•		22	1.098	3.9	.321	39	—	—	—	—	288	—	8.0
19N 20E 8DDB	•		8	.399	2	.164	41	—	—	.8	—	500	616	7.64
19N 20E 17ADDB	•		15	.748	6.3	.518	—	—	—	—	—	604	796	8.1
19N 20E 18BBA	•		4.8	.240	.7	.058	10	—	—	.3	—	264	321	8.25
19N 20E 18DB	•		4.2	.210	1.2	.099	18	—	—	.3	—	309	375	8.12
19N 20E 27AC	21	.537	107	5.339	41	3.372	88	—	—	.2	.2	1148	1600	7.4
19N 20E 30BC	9.5	.243	18	.898	.3	.025	94	—	49	2.5	.4	770	917	7.8
19N 20E 30DA	•		12.	.604	4.6	.378	43	—	—	.3	—	470	58	7.8
17N 20E 8	•		19	.948	13	1.069	—	.005	—	.9	—	226	—	7.49
17N 20E 9	•		27	1.347	9	.740	—	.005	—	.12	—	274	—	7.32
18N 19E 1	2	.051	32	1.597	15	1.234	—	.005	—	.3	—	308	—	7.99
18N 19E 7	•		19	.948	12	.987	—	—	—	.02	—	178	—	7.46
18N 19E 10AA	4.1	.105	18	.898	6.6	.543	76	—	—	.1	.4	272	237	7.6
18N 19E 12AD	2.9	.074	26	1.297	14	1.151	67	—	.02	.1	.4	308	309	7.0
18N 19E 12CB	3.3	.084	42	2.096	14	1.151	69	—	—	.4	.2	354	394	7.6
18N 20E 3BC	39	.998	71	3.543	27	2.220	49	—	127	.1	—	965	1428	8.1
18N 20E 6DB	5.1	.130	20	.998	13	1.069	81	—	.2	—	—	288	258	8.3
18N 20E 8AC	5.9	.151	17	.848	12	.987	75	—	—	—	—	254	236	8.6
18N 20E 8BB	5.9	.151	25	1.247	14	1.151	66	—	—	.1	.5	318	303	7.5
18N 20E 17	•		21	1.048	3	.247	—	.005	—	—	—	117	—	7.36
18N 20E 18	•		21	1.048	14	1.151	—	—	—	.15	—	199	—	7.46
18N 20E 20BB	6	.153	26	1.297	11	.905	57	—	.09	.2	.4	289	293	7.3
18N 20E 29	•		45	2.245	11	.905	—	.015	—	.01	—	343	—	7.97

APPENDIX VII (Continued)

Location	Source	Depth (feet)	Date of Collection	Analyst	Temp. (°C)	Bicarbonate mg/l	Bicarbonate epm	Carbonate mg/l	Carbonate epm	Chloride mg/l	Chloride epm	Sulfate mg/l	Sulfate epm	Sodium mg/l	Sodium epm
18N 20E 30CD	Well	300	02-11-58	USGS	19.4	162	2.655	—	—	2.90	.082	2.40	.050	24.5	1.066
18N 20E 34	Well	213	08-21-72	NSHD	18.9	122	2.000	—	—	8.0	.226	990	20.612	100	4.350
18N 20E 34	Well	110	03-05-71	NSHD	18.9	198	3.245	—	—	11	.310	340	7.079	37	1.610
18N 20E 34	Well	160	01-14-71	NSHD	11.7	242	3.966	—	—	7	.197	62	1.291	31	1.349
18N 20E 34A	Well	—	04-06-72	NSHD	15.6	181	2.967	—	—	6.0	.169	125	2.602	87	3.785
18N 20E 34AC	Well	136	01-27-58	USGS	15.6	162	2.655	—	—	7	.197	375	7.807	37	1.609
18N 20E 34DB	Well	136	01-27-58	USGS	18.9	198	3.245	—	—	7	.197	154	3.206	29	1.261
19N 18E 14	Well	391	12-13-72	NSHD	13.3	122	2.000	—	—	19	.536	49	1.020	35	1.523
19N 19E 1BA	Well	23	05-20-58	USGS	13.9	435	7.130	—	—	96	2.707	1680	34.978	400	17.400
19N 19E 4CC	Well	295	05-19-58	USGS	16.1	133	2.180	—	—	5.8	.164	173	3.602	25	1.087
19N 19E 10	Well	250	02-28-73	NSHD	15.6	115	1.885	—	—	6.0	.169	103	2.144	12	.522
19N 19E 10CC	Well	90	02-11-58	USGS	12.8	233	3.819	—	—	3.4	.096	8.2	.171	19	.826
19N 19E 11DA	Well	352	1958	NSHD	13.9	154	2.524	—	—	10	.282	41	.854	13	565
19N 19E 11DB	Well	190	02-27-46	NSHD	12.8	162	2.655	—	—	14	.395	46	958	28	1.218
19N 19E 12AA	Well	583	06-02-58	USGS	13.9	240	3.934	—	—	14	.395	69	1.437	23	1.000
19N 19E 12BCD	Well	322	06-03-61	—	17.2	156.2	2.566	—	—	12	.338	69	1.437	29.10	1.266
19N 19E 13BC	Well	213	05-21-58	USGS	18.3	176	2.885	—	—	6.7	.189	38	.791	16	696
19N 19E 17AD	Well	70	08-07-47	NSHD	14.4	427	6.999	—	—	25	.705	98	2.040	68	2.958
19N 20E 2AD	Well	210	05-13-58	USGS	16.7	128	2.089	—	—	24	.677	59	1.228	59	2.566
19N 20E 3CA	Well	213	02-13-58	USGS	14.4	76	1.246	16	.533	6.5	.183	66	1.374	25	1.087
19N 20E 4DC	Well	407	07-18-58	BCSF	14.4	112	1.836	—	—	5.0	.141	49	1.020	30	1.305
19N 20E 6BB	Well	147	05-20-58	USGS	14.4	246	4.032	—	—	21	.592	144	2.998	52	2.262
19N 20E 8AC	Well	41	01-14-58	USGS	11.7	155	2.540	—	—	7.4	.209	11	229	12	.522
19N 20E 8AD	Well	18	02-13-58	USGS	12.2	135	2.213	—	—	170	4.794	14	291	94	4.089
19N 20E 8BDD	Well	305	10-18-66	—	17	107	1.754	—	—	4	.113	36	.750	23	1.001
19N 20E 16AC	Well	300	05-11-56	USBR	13.9	104	1.705	3.6	.120	12	.338	111	2.311	75	3.262
19N 20E 16CD	Well	210	05-11-56	USBR	11.7	97	1.590	8.4	.280	13	.367	120	2.498	91	3.958
19N 20E 19AB	Well	197	01-14-58	USGS	15.6	139	2.278	—	—	7.8	.220	39	812	25	1.087
19N 20E 19CB	Well	24	01-13-58	USGS	19.4	222	3.639	—	—	20	.564	174	3.623	120	5.220
19N 20E 20ADD	Well	204	11-09-60	—	15.5	170.8	2.799	—	—	5.0	141	16.0	.333	43.9	1.910
19N 20E 20DA	Well	61	01-13-58	USGS	10.6	181	2.967	—	—	5.1	.130	51	.130	48	2.088
19N 20E 21BCB	Well	562	11-12-59	—	18.8	174.5	2.860	—	—	18	508	143.2	2.981	130.1	5.659
19N 20E 22DA	Well	75	08-13-59	USGS	17.8	83	1.360	—	—	315	8.883	175	3.643	140	6.090
19N 20E 30DA	Well	83	01-13-58	USGS	12.2	256	4.196	—	—	4.5	.127	26	.541	31	1.348
19N 20E 31	Well	40	06-19-73	NSHD	10.0	256	4.196	—	—	6.0	.169	28	.583	29	1.261
19N 20E 31AAAB	Well	—	03-23-63	NSHD	13.3	405	6.638	—	—	9	.254	24	500	35.74	1.555
19N 20E 31DA	Well	139	05-08-56	USBR	15.6	121	1.983	6.3	.210	1.4	.039	3.4	.071	12	.522
19N 20E 32AA	Spring	—	05-11-56	USBR	15.6	149	2.442	18	.600	2.8	.079	6.2	.129	18	.783
19N 20E 33BC	Spring	—	05-11-56	USBR	18.3	145	2.377	20	.667	7.1	.200	7.2	.150	34	1.479
19N 20E 33BD	Well	70	05-13-58	USGS	14.4	260	4.261	—	—	62	1.748	18	375	75	3.262
19N 20E 33BD	Spring	—	05-13-58	USGS	16.7	207	3.393	—	—	29	.818	15	312	60	2.610
20N 20E 31DD	Well	66	05-20-58	USGS	13.3	289	4.737	—	—	20	.564	239	4.976	56	2.436
20N 20E 33CB	Well	85	05-13-58	USGS	13.3	397	6.507	—	—	7	.197	82	1.707	92	4.002
20N 20E 34BC	Well	39	02-13-58	USGS	10.0	185	3.032	—	—	18	.508	271	5.642	43	1.870

BCSF = Brown and Caldwell Co., San Francisco, CA
NSHD = Nevada State Health Division
USBR = U.S. Bureau of Reclamation
USGS = U.S. Geological Survey

APPENDIX VII (Continued)

Location	Potassium mg/l	Potassium epm	Calcium mg/l	Calcium epm	Magnesium mg/l	Magnesium epm	Silica mg/l	Arsenic mg/l	Boron mg/l	Fluoride mg/l	Lithium mg/l	Total Dissolved Solids (sum of mg/l)	Specific Conductance (umhos/cm @ 25°C)	pH
18N 20E 30CD	*		26	1.297	4.90	.403	29	—	.05	—	—	256	—	7.4
18N 20E 34	*		237	11.826	80	6.579	—	—	—	.65	—	1542	—	7.04
18N 20E 34	*		123	6.138	36	2.961	—	—	—	.27	—	752	—	7.38
18N 20E 34	*		64	3.194	11	.905	—	—	—	.17	—	417	—	7.64
18N 20E 34A	*		27	1.347	8	.658	—	—	—	—	—	436	—	7.9
18N 20E 34AC	2.1	.054	120	5.988	36	2.961	41	—	.02	.2	—	784	930	7.1
18N 20E 34DB	4.2	.107	71	3.543	20	1.645	22	—	.04	.2	—	508	609	7.2
19N 18E 14	*		21	1.048	9	.740	—	—	—	.21	—	263	—	7.18
19N 19E 1BA	4	.102	354	17.665	137	11.267	59	—	.34	.2	1.2	3278	3780	7.6
19N 19E 4CC	1.0	.026	62	3.094	20	1.645	29	—	—	.1	.4	450	593	7.9
19N 19E 10	*		45	2.245	18	1.480	—	—	—	—	—	304	—	7.66
19N 19E 10CC	2.5	.064	42	2.096	14	1.151	34	—	.03	—	.3	358	389	7.6
19N 19E 11DA	*		41	2.046	14	1.151	—	—	—	—	—	289	—	—
19N 19E 11DB	*		36	1.796	10	.822	18	—	—	—	—	314	—	—
19N 19E 12AA	2.2	.056	71	3.543	17	1.398	45	—	.03	.1	.4	490	571	7.9
19N 19E 12BCD	*		38.8	1.936	13.9	1.143	21.9	—	—	.2	—	343	392	7.4
19N 19E 13BC	3.2	.082	38	1.896	16	1.316	33	—	.01	.1	.4	331	388	8.0
19N 19E 17AD	*		96	4.790	24	1.974	38	—	—	—	—	776	—	—
19N 20E 2AD	3.2	.082	21	1.048	34	.280	19	—	.01	.1	.4	319	433	8.2
19N 20E 3CA	6.1	.156	28	1.397	7.4	.609	48	—	—	.6	.7	281	323	8.8
19N 20E 4DC	*		21	1.048	8.1	.666	49	—	.10	.15	—	275	270	7.8
19N 20E 6BB	4.1	.105	69	3.443	26	2.138	52	—	—	.1	.4	628	746	7.9
19N 20E 8AC	2.6	.067	32	1.597	11	.905	37	—	—	.2	.3	274	316	7.6
19N 20E 8AD	4.6	.118	42	2.096	13	1.069	39	—	—	.6	.5	517	875	8.1
19N 20E 8BDD	*		19	.948	8	.658	46	—	—	.5	—	244	255	7.85
19N 20E 16AC	7	.179	11	.549	6.5	.535	52	—	.34	—	—	383	459	8.2
19N 20E 16CD	6.3	.161	7.4	.369	3.8	.313	54	—	.40	.7	—	402	490	8.5
19N 20E 19AB	5.1	.130	28	1.397	7.7	.633	48	—	.24	.1	.2	304	341	8.0
19N 20E 19CB	9.5	.243	40	1.996	5.0	.411	101	—	—	1.2	.4	700	795	7.5
19N 20E 20ADD	*		18.8	.938	5.2	.428	26.2	—	—	.3	—	287	295	7.6
19N 20E 20DA	5.1	.130	26	1.297	7.6	.625	75	—	.15	.6	—	403	432	7.5
19N 20E 21BCB	*		7.9	.394	3.8	.313	31	—	—	.3	—	510	611	8.1
19N 20E 22DA	8.8	.225	85	4.241	39	3.207	15	—	6.1	.1	.0	869	1460	7.8
19N 20E 30DA	5.6	.143	33	1.647	21	1.727	71	—	—	.1	.5	453	510	7.0
19N 20E 31	5.0	.128	43	2.146	24	1.974	—	—	—	.09	—	391	—	7.59
19N 20E 31AAAB	*		59.26	2.957	35.06	2.883	—	—	—	—	—	568	—	7.72
19N 20E 31DA	5.1	.130	16	.798	13	1.069	77	—	.00	.0	—	256	240	8.5
19N 20E 32AA	5.1	.130	24	1.198	14	1.151	90	—	.00	.0	Tr	328	301	8.7
19N 20E 33BC	5.9	.151	20	.998	12	.987	93	—	.18	.0	.0	345	322	8.8
19N 20E 33BD	8.0	.205	36	1.796	13	1.069	68	—	.85	.2	1.4	548	656	7.8
19N 20E 33BD	4.9	.125	21	1.048	8.7	.715	67	—	.87	.2	.9	416	444	7.8
20N 20E 31DD	2.6	.067	122	6.088	24	1.974	54	—	.24	.2	.5	819	979	7.4
20N 20E 33CB	3.8	.097	62	3.094	15	1.234	53	—	1.1	.3	.4	723	794	7.9
20N 20E 34BC	3.6	.092	92	4.591	34	2.796	53	—	—	.3	.4	705	918	7.5

*Difference between anions and cations, in epm, assumed to be sodium and potassium and calculated as sodium.

Tr = Trace